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Foreword

This report contains five papers dealing with the subject of pricing transportation systems. Economic considerations have been utilized in determining transportation route locations but have not received substantial considerations in determining the pricing or the controlling of the demand of services. Pricing has been principally determined by the cost of construction and technological hardware. With the rapid urbanization throughout the world in recent decades, there is growing congestion of transportation facilities in urban areas. Transportation technology has developed a high-speed hardware, but congestion of the transportation facilities caused by overloading has resulted in hardware being used at less than designed speeds, traffic congestion occurring during peak hours, and time delays being experienced by all users indiscriminate of value or purpose of trip. Recently, economists have begun considering the possibility of applying variable pricing techniques to reduce the flow, thereby reducing congestion, of traffic at peak loading periods in urban areas.

The papers in this RECORD were generated from a Conference Session at the 48th Annual Meeting of the Highway Research Board. The Conference was instituted to bring a number of economists together to discuss the relationship between pricing and the use of transportation systems. The papers presented imply that time delays caused by congestion are very costly, and the time delays may be minimized through variations in pricing structure to adjust demands to the capacity of the fixed transportation facility.

Joseph Yance discusses the use of pricing to reduce airport congestion. Like other transportation facilities, airlines have peak-use patterns. Yance points out that the trouble lies in the nature of the costs and incentives that are presented to the traveler. Part of the problem is that the cost of increased movements above the capacity of the system do not necessarily fall on each individual or airline using the system but are distributed to all users of the system. One solution to the problem is to charge a "congestion toll" equal to the cost of the delay that the marginal user imposes on others. Yance then goes on to discuss how congestion pricing is being used and could be used in controlling airline movements at congested hub airports such as National Airport in Washington, D. C.

Gabriel Roth, in his paper on "The Pricing of Road Transport Services in Developing Countries," points out that pricing of transportation services can fulfill four functions: (a) rationing of available resources among potential users, (b) providing funds from which transportation services can be met, (c) distributing income by supplying costly transportation services at low prices to the needy, and (d) enabling authorities to levy taxes. The use of scarce resources, he says, is encouraged by low prices and discouraged by high ones. He then discusses methods for applying congestion pricing.

Charles Hedges, in his paper on "An Evaluation of Commuter Transportation Alternatives," develops a framework to evaluate various solutions that are proposed to eliminate rush-hour congestion. The suggested alternatives are grouped into three categories: price changes, institutional changes, and other factors. He also points out, as was done in some of the other papers, that the current pricing mechanism does not charge the road user with the marginal social costs incurred by congestion. Special tolls would satisfy the efficiency criterion although they are not politically feasible. Hedges raises the question of whether transportation planners and administrators adequately inform the public of the true costs and benefits of transportation and the possible alternatives available to them.

Alexander Morton attempts to demonstrate a model for measuring the demand for intercity freight traffic. He shows the relationship between freight rate policies pursued by the two dominant freight modes during the postwar period and extrapolates these facts into tentative recommendations for future policies for both carriers and federal administrative agencies.

Similarly, Charles Howe and Robert Steinberg, in their report on "The Structure of Congestion Costs and Optimum Pricing in Inland Waterway Transportation," describe the nature of a computer simulation model that analyzes the congestion costs and benefits accruing from improvements to inland water transportation systems. As on highways, congestion frequently occurs on major rivers of the United States. Similarly, analysis of the impact of structural improvement to the navigational systems will have an effect on waterway congestion. The efficient use of waterways in the face of congestion requires the pricing of services of waterways in such a way that the prices charged reflect congestion conditions.

Contents

Pricing to Reduce Airport Congestion

JOSEPH V. YANCE, Department of Economics, Boston University

•INTUITIVELY, it seems clear that congestion is wasteful—that having people and capital tied up in commuter rush hours and in long delays at airports waiting to land or take off does not represent a useful employment of these resources. Yet, in spite of this, congestion continues.

The trouble lies in the nature of the costs and incentives that are presented to the traveler or common carrier. For example, as the hourly movement rate at an airport increases, the average delay increases. The individual airline feels the cost of the average delay; however, what it does not feel is the increase in delay that an additional movement imposes on others. In other words, part of the cost of an additional movement is an "external" cost not felt by the user himself, but imposed on other users. An individual will, therefore, continue to use the facility even though the total extra cost to himself and society is greater than the value of the trip.

Economists pointed out this problem at least as long ago as 1924 and indicated a solution: Charge a "congestion toll" equal to the cost of the delay that the marginal user imposes on others. If the individual has to pay a toll equal to the external cost, then he will not use the facility unless the value of use is at least as great as the incremental cost to society. The use of the facility will then be "economically efficient."

APPLICATION TO WASHINGTON NATIONAL AIRPORT

To get an empirical idea of movement rates, average delays, and marginal external delays, consider Table 1. The table is based on a regression analysis of delay data at Washington National Airport obtained during a one-week survey in 1967 (1). The data are for a typical combination of aircraft that use the airport, 60 percent carrier aircraft and 40 percent general aviation (small planes). The average delay refers to the average delay for planes waiting to take off, or the time spent in holding patterns waiting to land. The marginal external delay shows the delays that a single movement imposes on other users. Thus, at a movement rate of 75 aircraft per hour, which is considered to be about the capacity of the airport, the average delay is estimated to be 3.6 min; the delay a carrier movement imposes on other aircraft is 14.3 min (considerably larger than that the aircraft itself incurs). Other figures pertain to general aviation movements, and to delays and external delays at night.

At Washington National a partial quota system has been in effect for two years. It affects mostly scheduled flights; extra sections of shuttle flights are permitted beyond the quota, and the restrictions have never really been applied to general aviation. But as a result of the restrictions, the number of flights is undoubtedly much less than it would be if the scheduled air carriers were permitted free access to the airport.

I think the external costs under present conditions give some indication of the congestion fees that would be appropriate under a pricing solution. Before discussing the figures, I might mention that the present landing-fee policy is based on the gross landing weight of the airplane—30 cents per thousand pounds for jet aircraft, and 15 cents per thousand pounds for propeller aircraft with a minimum fee of $4.00. Thus the landing fee ranges from $6 for an F-227 to $40 for a B-727, and averages about $20 for carrier aircraft. The landing fee covers both the landing and takeoff, so the average fee per movement is about $10.

Paper sponsored by Committee on Socio-Economic Aspects of Highways and presented at the 48th Annual Meeting.

TABLE 1

AVERAGE DELAY AND MARGINAL EXTERNAL DELAY (MED)
(Minutes)

Movements/ hour	Daylight			Dark		
	Avg. Delay	MED/Movement		Avg. Delay	MED/Movement	
		Carrier[a]	Gen. Av.[a]		Carrier[a]	Gen. Av.[a]
40	0.78	1.69	0.86	1.47	3.19	1.62
50	1.21	3.27	1.67	2.29	6.18	3.15
60	1.86	6.04	3.09	3.52	11.41	5.84
65	2.32	8.16	4.17	4.38	15.41	7.88
70	2.88	10.90	5.58	5.44	20.59	10.54
75	3.585	14.31	7.32	6.78	27.03	13.83
80	4.46	18.76	9.60	8.43	35.44	18.13
90	6.89	38.41	19.65	13.02	72.56	37.12

[a] 60 percent of aircraft that use airport is carrier; 40 percent is general aviation.

Let us compare this with current external costs. Table 2 gives the amount of traffic on an average weekday and the external costs caused by a carrier movement. In estimating these costs, we have assumed that carrier aircraft cost $300 per hour to operate and that each aircraft carries 50 passengers, whose time is worth $4 an hour, for a total cost of plane and people of $500 per hour. For general aviation planes, a total cost figure of $50 per hour has been used.

The external costs under present conditions, therefore, range from about $24 during the 7:00 a. m. hour to $139 during the 5:00 p. m. hour. The figures indicate what I think would be good estimates of congestion tolls for an initial trial. Thus, in place of fees averaging $10 per movement for carrier aircraft, we might have fees of from $40 to $125 per movement for carrier aircraft. Fees of this magnitude would probably go a long way toward making the quotas unnecessary.

Figure 1 shows the pattern of external costs during the day along with a smoothed out version of the curve, which is a suggested fee schedule with three discrete levels—$40, $75, and $125 per carrier movement. According to our analyses, a small plane costs, in terms of the delays it imposes on other users, about half as much as a carrier plane. Small planes should, therefore, pay fees equal to half those of carrier planes.

TABLE 2

AVERAGE WEEKDAY MOVEMENT RATES AND EXTERNAL COSTS

Hour	Movements/Hour[a]			External Cost/ ACR Movement	Suggested ACR Fee/Movement
	ACR[b]	Non-ACR	Total		
7:00 a. m.	38.4	7.8	46.2	$23.97	$40
8:00 a. m.	39.6	28.2	67.8	48.66	40
9:00 a. m.	45.0	31.4	76.4	80.80	75
10:00 a. m.	44.2	16.4	60.6	48.69	40
11:00 a. m.	43.6	16.4	60.0	46.50	40
12:00 noon	42.8	19.6	62.4	48.13	40
1:00 p. m.	37.8	18.8	56.6	31.85	40
2:00 p. m.	38.4	19.4	57.8	34.01	40
3:00 p. m.	38.2	23.2	61.4	37.53	40
4:00 p. m.	43.8	31.2	75.0	73.40	75
5:00 p. m.	46.0	25.8	71.8	139.37	125
6:00 p. m.	45.6	21.4	67.0	118.66	125
7:00 p. m.	40.8	15.6	56.4	69.20	75
8:00 p. m.	42.8	11.6	54.4	71.63	75
9:00 p. m.	44.2	6.6	50.8	68.68	75
10:00 p. m.	35.6	4.8	40.4	33.00	40

[a] Average hourly movement rates, Monday through Friday, November 13 through 17, 1967.

[b] Carrier aircraft.

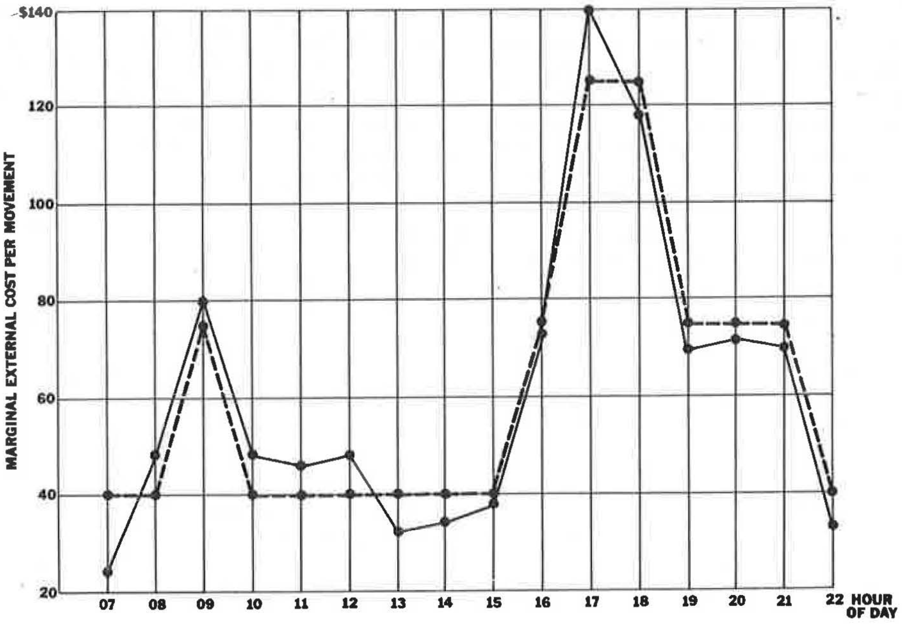

Figure 1. Marginal external cost per air-carrier movement and suggested fee per movement for congestion pricing.

ADVANTAGES OF A PRICING SOLUTION

A promising step toward the use of congestion pricing was taken in 1968 when the Port of New York Authority increased its minimum landing fee from $5.00 to $25.00 during peak hours at the three major New York airports. The fee increase has resulted in a decrease of about 25 percent in general aviation traffic at the three airports.

At the time the change was announced, Transportation Secretary Boyd issued a press release in which he tentatively approved the increase, but suggested that peak-hour fees should apply to carriers as well as to general aviation. The initiative for setting fees rests with individual airport authorities. The Federal Aviation Administration (FAA) and the U. S. Department of Transportation require that fees be nondiscriminatory, but the Secretary's statements indicate that congestion fees would not, on their face, be considered discriminatory.

Nevertheless, for various reasons (including the fact that some of the airports are tied to long-term contracts with the airlines) airport authorities have not moved very fast in adopting landing-fee policies to reduce congestion. When the delays at the major airports increased substantially, the FAA moved to introduce a quota system for reducing congestion.

The quotas, which were effective as of June 1, 1969, established hourly movement limits at the New York, Washington National, and O'Hare Airports. The quotas required large reductions in the number of general aviation flights and, to a smaller extent, carrier flights. The quota system that has been in effect at Washington National during the last two years has not worked too badly, but there are some objections to the new quota system that should be mentioned. I think that on three points a quota system is inferior to a pricing solution.

First, it is very difficult to implement a quota system. The one in effect at Washington National was relatively easy to work out because schedules are essentially the same for five days of the week. There are only about a dozen airlines involved, and they are able to effect changes in schedule slots through horse-trading. This sort of bargaining becomes increasingly difficult as the number of airports and number of airlines involved increase.

For example, the director of scheduling for American Airlines mentions the case of one of his planes that goes from Washington to Chicago to New York and back to Chicago. A change in schedule for this one plane might require the concurrence of scheduling committees in each of three cities (2). The committee of airlines in New York must attempt to allocate slots for 40 airlines whose schedules are variable during the week, requiring practically day-by-day allocation. There is, furthermore, no guarantee that such allocation will lead to efficient use of airport capacity. (For example, the shuttle was arbitrarily threatened by the quota system.)

Even if efficient schedules can be devised, a second question needs to be considered: Will the quota system lead to a distribution of income that we consider to be good? The scarce factor here is primarily airport capacity. When a factor is scarce, in a normal market situation, its price is bid up, and the "scarcity rents" go to the owners of the factor. Here, however, the rights to scarce airport capacity are being awarded to the airlines; they will get the scarcity rents. The question of who should obtain these rents is a matter of choice; I would prefer to see them go to the local communities, rather than to the airlines.

Finally, I think that alternative methods of allocating airport capacity should be examined in a long-run context. At present, it seems that New York and Chicago each need another airport. However, the demand is somewhat overstated; there is excess demand in part because the users of the present airport are not required to pay the costs they are imposing. But suppose that, taking this into account, there is need for another airport in each of the two cities. The new airports being proposed are 30 or 50 miles out of the city. If those airports are built, a way to ensure their utilization is through some sort of price policy where considerable rents are earned at the close-in airports. Otherwise, we can have a case similar to that in Washington, where congestion persists at the close-in airport while the outlying airports are underutilized.

In summary, with a fee schedule based on external costs, first, the most valuable uses of the airport could be sorted out with a minimum of government intervention and airline collusion; second, the local community would have, what I think is deserved, a new source of revenue; and third, we would have a market test of the need for new airports and a system that would guarantee that, if those airports are built, they will be used.

ACKNOWLEDGMENT

The views expressed in this paper are those of the author and do not represent the policy of the U. S. Department of Transportation.

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The Pricing of Road Transport Services in Developing Countries

GABRIEL ROTH, International Bank for Reconstruction and Development

•THE PRICING of transport services can fulfill the following four functions: (a) ration available resources among potential users, (b) provide a fund from which the cost of transport services can be met, (c) redistribute income by supplying costly services at low prices to needy people, and (d) enable the authorities to levy taxes.

It is generally agreed that cheap transport services are an inefficient way of helping the needy: inefficient in the sense that, for a given expenditure, it is possible to give more effective help to the needy in other ways, for example, by family allowances. This aspect of pricing will, therefore, not be discussed here further.

Nor will the use of transport prices to raise taxation be discussed further. In some fields, particularly the pricing of roads, there is no clear distinction between the amounts paid by users to cover economic costs and the amounts paid as tax revenues. But it is important to make this distinction. This survey will attempt to apply the economic principles that govern the optimal use of resources to the determination of the prices appropriate to road transport services. Once these prices are established, it is always open to a community to adjust them by the imposition of taxes or the granting of subsidies, in accordance with the general principles of taxation.

PRICING TO RATION SCARCE RESOURCES

The use of any scarce resource is encouraged by low prices and discouraged by high ones. If we were interested only in the rationing effect of prices (in making the best use of the scarce resource), we would charge every user the costs arising out of his or her use, no more and no less. The costs arising out of use consist of two separate elements: (a) costs imposed on the supplier of the transport service as a result of resources directly consumed such as wages, fuel, wear and tear—these can be called direct costs; and (b) costs imposed on other users such as congestion or rental costs—these can be called congestion costs.

The price equal to these costs will be referred to here as the economic user charge. Thus, by definition, economic user charge = direct costs + congestion costs. [This expression is used by Walters (1); a corresponding expression, economic charge = cost charge + congestion charge, is used in the Allais Report (2).]

Where there is no congestion, the economic user charge will consist only of the direct costs, i.e., of the value of the resources directly consumed as a result of the provision of the good or service in question. If, when the direct cost is charged, the demand for the facility exceeds capacity so that potential users have to queue or squeeze up, the economic user charge must include an additional element to balance supply and demand. This element, which represents the congestion costs imposed on other users, is in the nature of a scarcity rent.

To illustrate the argument, consider the appropriate economic user charges for (a) the hire of a truck, (b) the use of a metered parking space, and (c) the use of a road.

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Hire of a Truck

Any journey made by a truck will result in additional money costs to the owner such as the costs of fuel, oil, and tire wear. These direct costs are known, and no rational owner would hire out his truck if they were not covered. As long as they are covered, any price that will contribute something extra toward overhead is worth having. Therefore, as long as haulage prices are such that direct costs are covered, the truck will move. If the contributions to overhead are not high enough to meet all the costs of the truck owner, the truck will not move for long; some owners will be forced out of business. This will reduce the haulage capacity available and increase the prices obtainable by other truckers. The trucking fleet will become smaller but more profitable. If, on the other hand, the haulage rates obtainable by a trucker are high enough to meet all his overhead and to give him exceptionally high profits, it is likely that other truckers will enter the business, push down the rates, and make the industry bigger and less profitable. The trucker will generally charge as much as the market will bear, which is the economic user charge and which may or may not cover his total costs. In the short run, the prices charged by haulers will be determined by the demand-and-supply conditions in the market and not by the total costs of trucking firms.

If entry into the industry is restricted by monopoly or by governmental regulation, those fortunate enough to be in the business will earn abnormal profits. But as long as rates are determined by supply and demand, they could be regarded as the economic user charges appropriate to the situation prevailing in the absence of a competitive market.

Use of a Metered Parking Space

The economic user charge for metered parking spaces should not be less than the direct cost of operating the meters. If at this price the demand for spaces exceeds the supply, the economic user charge will be the price at which supply and demand roughly balance, i.e., the price at which there is an acceptable probability that casual parkers will be able to find spaces readily. If the price were to be pitched too high, so that there were always large numbers of parking spaces vacant, the vacant parking spaces would represent a waste of resources. If the price were pitched so low that there were many people looking for spaces for long periods, the price would not succeed in the object of allocating the spaces quickly to those prepared to pay for them. The British Ministry of Transport suggests that the optimum utilization of meter bays is about 85 percent, with 15 percent available at any one time.

As demand fluctuates from place to place and from time to time, it cannot be expected that any one price will result in a utilization of 85 percent, or any other desired figure. It is desirable to charge different prices for different areas, to vary prices with the time of day and the time of year, to introduce as much flexibility as possible into parking charges, and to fix rates that are a sensible compromise between the ideal in theory and the achievable in practice.

This is not the place to discuss in detail the problem of charging for parking (4). The purpose of mentioning the subject is to give an example of a transport service where quite clearly the economic user charge bears no relationship to the direct cost of supplying the service, which is often small compared to the rental value of the land. The main economic cost of parking in city centers is that other would-be parkers or land users are deprived of the use of the space; the economic user charge is determined by the pressure of demand on a limited supply of space.

Use of a Road

In the previous examples, the capacity of both the truck and the parking space is fixed; the truck can usually accommodate one truckload and the parking space just one vehicle. The capacity of a road is, however, variable. It can carry few or many vehicles at different levels of service. At low traffic volumes vehicles do not interfere with one another and do not increase the costs of one another. But as traffic volumes rise, delay costs become of increasing importance. These costs include loss of time, higher fuel and running costs, and lower utilization of vehicles and their loads. What then is the appropriate economic user charge?

At low volumes, where vehicles do not impose costs upon one another, the economic user charge is the direct cost, i.e., the costs to the highway authority that arise out of the use of the road system. As and when roads become congested, the economic user charge should include an element to reflect the congestion costs imposed on other road users in order to bring about the optimal use of the road. The principle of charging for the use of congested roads, and the methods that might be employed, have been discussed elsewhere (1, 2, 3, 4, 5, 6). Congestion costs arise out of scarcity, the scarcity of road space. This scarcity can enable the owners of a congested road to levy a rent on the users, a rent equivalent to the rents chargeable by land owners, theatre and hotel operators, and all who own scarce resources and make them available to others. It is evident that the benefits obtainable from a congested road are largest when the rent required from each user just equals the congestion costs resulting from his presence. For if the rent demanded falls short of the congestion costs imposed, some users will be attracted to the road even if the benefits to them fall short of the costs inflicted by them on others. And if the rent demanded is in excess of the costs imposed on others, some potential users will be unnecessarily debarred from using the road.

The imposition of extra taxes on congested roads has been attacked as unfair, on the grounds that road users already pay for congestion in terms of delay and frustration, and that the imposition of a congestion tax would add insult to injury. But this objection, though at first sight reasonable, cannot be sustained. Those who have to take their holidays in the summer have to put up with congestion and with high hotel charges. These high seasonal charges encourage those who can take their holidays off-season to do so, and in this respect those who must holiday in the summer are relieved of congestion. Insofar as the summer peak cannot be shifted, the peak charges enable the hotels to provide the facilities that are required only by the peak users. The imposition of additional charges at peak times is beneficial as it promotes the better use of scarce resources. Peak charges are taken for granted in the telephone and electricity services, although for good psychological reasons they are described in terms of off-peak reductions rather than of peak-hour increases. But the principle is the same.

PRICING TO MEET TOTAL COSTS

Hitherto the argument has been concerned with the rationing function of pricing in making the best use of existing resources. The second function, raising sufficient funds to pay for the provision of transport facilities, has not been dealt with. In the case of the truck we saw that if the revenues being earned from the use of scarce resources are large enough to give big profits to operators, further resources are attracted to the industry, which tends to become larger and less profitable. Conversely, if revenues are insufficient to cover total costs, some vehicles drop out; and the industry becomes smaller and more profitable. This suggests that for any facility, including a road, there will be an optimal size and level of congestion at which, if the economic user charge is levied, the costs of the facility are just balanced by payments from users. If a facility is of the optimal size, the economic user charge will serve two functions: (a) ration available road space in the most efficient manner, and (b) raise sufficient funds to cover total costs. Economies or diseconomies of scale in highway construction would require this conclusion to be modified without, however, affecting the basic reasoning.

The economic user charge does not include an element to meet fixed costs, i.e., costs that do not arise directly out of use. Under the optimal conditions described above, the revenues from congestion charges will exactly balance the fixed costs, and the facility will break even. If there is more than optimal congestion, the levying of the economic user charge will produce a financial surplus, indicating that expanding the congested facility is in order. If there is no congestion, the economic user charge will not cover fixed costs; the implications of this are discussed below.

THE PRICING OF CONGESTED ROADS

A number of cheap and simple methods of taxing vehicles under conditions of congestion were described in the Smeed Report on road pricing (5). One method required that each vehicle have mounted on it a meter that would be actuated by signals from the road at different "pricing points." Another method was based on continuous pricing while vehicles are traveling in defined "pricing zones," payment being made by the purchase of "throw-away" electrolytic timers (such as special batteries) that would be activated in the pricing zones and discarded when exhausted. Yet another method was based on the idea of a daily license or "sticker" that would have to be used in congested areas. The Smeed Committee described 6 meter systems that, it considered, might be developed into effective charging methods.

The Committee's examination of charging methods was based on 17 "operational requirements for a road pricing system," which it laid down, and on a cost target of $5 per vehicle per year for the meters. The Committee also examined the likely road prices that would be required, and suggested that 10 shillings an hour ($1.20 at the current exchange rate) might be the appropriate price for a private car in central London where present traffic speeds are 10 mph. It reckoned that the effect of such a charge could be to reduce traffic volumes and to raise speeds by 20 to 25 percent. It suggested that slow or bulky vehicles should be charged more than private cars, in proportion to the congestion caused.

The technical conclusions of the Smeed Report do not appear to have been challenged, and work on the development of pricing equipment is proceeding in Britain. It may, therefore, be assumed that there are no major technical difficulties in levying a congestion tax roughly approximating the congestion costs imposed on other road users. There would, of course, be political difficulties, but these need not be insuperable, particularly if the revenues are used to expand the highway systems in the congested areas.

Pricing the use of congested roads may be particularly appropriate in developing countries that are often short of capital for investment; their needs are large and their current surpluses small. Yet many of them suffer from excessive traffic congestion in places; even the sparsest areas appear to support substantial numbers of people who possess motor cars. In such situations, the use of congestion charges to finance road schemes could make a particularly valuable contribution to the developing country. Furthermore, developing countries are in a more suitable psychological condition to introduce new road-charging methods than are developed ones, whose charging methods were devised before the economics of traffic congestion were generally understood. Developing countries need not be hampered by traditional attitudes in their search for the most efficient methods of financing roads.

THE PRICING OF UNCONGESTED ROADS

One of the characteristics of roads in developing countries is that many of them are not congested and, if subject to the economic user charge, would not earn enough revenues to cover their total costs. This problem arises essentially from the "lumpiness" of roads, which have to be built to minimum standards for physical reasons. A road 20 ft wide carrying 100 vehicles a day may be uncongested and, therefore, in the economic sense, too large. Unfortunately it is not possible to move the same traffic on a road 2 ft wide that is filled to its optimal economic capacity by 1,000 vehicles, each under 1 ft wide; the choice often lies between having a road with excess capacity or having no road at all.

The following questions arise: (a) What is the economic user charge for an uncongested road? (b) How can it be collected? (c) If the economic user charge is insufficient to cover total costs, how is the road to be paid for?

Before these questions are considered, it is necessary to see the order of magnitude of the costs involved. Both the construction and the maintenance costs of roads vary widely with terrain, climate, and type of construction. The data from Venezuela (7) can be used for illustration. Soberman distinguished between construction and

TABLE 1

ROAD COSTS AT DIFFERENT TRAFFIC VOLUMES[a]
(U.S. dollars per km per year)

ADT	Type of Cost	Type of Road					
		Earth		Gravel		Bituminous	
		Amount	Percent	Amount	Percent	Amount	Percent
50	Construction	301	24	603	31		
	Fixed maintenance	335	27	1, 161	59		
	Variable maintenance	602	49	201	10		
	Total	1, 238	100	1, 965	100		
200	Construction	301	10	603	24	3, 000	56
	Fixed maintenance	335	11	1, 161	45	2, 322	43
	Variable maintenance	2, 410	79	804	31	44	1
	Total	3, 046	100	2, 568	100	5, 366	100
800	Construction			603	12	3, 000	55
	Fixed maintenance			1, 161	23	2, 322	42
	Variable maintenance			3, 216	65	176	3
	Total			4, 980	100	5, 498	100
1, 600	Construction					3, 000	53
	Fixed maintenance					2, 322	41
	Variable maintenance					352	6
	Total					5, 674	100

[a] From Soberman (7).

maintenance costs, and divided the maintenance costs into their fixed and variable components. The fixed maintenance costs were those "largely independent of traffic density ... caused primarily by climatic factors and ... vegetation"; variable maintenance costs were those depending primarily on "traffic intensity and the frequency of heavy trucks."

Construction costs in U.S. dollars per kilometer for two-lane roads, 7.2 meters wide, were found to be:

For earth roads,	$ 3,010
For gravel roads,	$ 3,350
For paved (bituminous) roads,	$25,000 to $45,000

Maintenance costs were found to be:

$$M_E = 335 + 12.05\,(\text{ADT})$$

$$M_G = 1{,}161 + 4.02\,(\text{ADT})$$

$$M_P = 2{,}322 + 0.22\,(\text{ADT})$$

where M_E, M_G, and M_P represent the costs in U.S. dollars per year of maintaining one kilometer of earth, gravel, and paved road respectively, and ADT represents the average daily traffic.

By converting the construction cost to an equivalent annual amount, assumed to be one-tenth of the whole, it is possible to express all these costs in terms of U.S. dollars per year for different average daily traffic flows. Costs for ADT's of 50, 200, 800, and 1,600 are given in Table 1, which also gives the percentage that construction costs, fixed maintenance costs, and variable maintenance costs are of total costs. Over the relevant ranges, construction costs account for 56 to 53 percent of the total costs of paved roads; 31 to 12 percent of the costs of gravel roads; and 24 to 10 percent of the costs of earth roads. The remaining costs are maintenance costs, but variable maintenance costs (i.e., maintenance costs that result directly from the movement of vehicles) account for 1 to 6 percent of total costs of paved roads, 10 to 65 percent of gravel roads, and 49 to 79 percent of earth roads.

THE ECONOMIC USER CHARGE FOR AN UNCONGESTED ROAD

Walters (1) holds that variable maintenance costs, because they are the only costs arising from a journey, constitute the economic user charge. Others argue that because all maintenance costs can be avoided in the short run (by a decision to cease maintaining the road), all maintenance costs should be included in the economic user charge. Economists appear to agree that the economic user charge includes the variable maintenance costs and excludes the sunk construction costs. The disagreement on the treatment of fixed maintenance costs is of practical importance because these costs can be a major element in the expenditure on gravel roads (Table 1).

COLLECTING THE ECONOMIC USER CHARGE

The obvious candidates for meeting the costs of uncongested roads are fuel and tire taxes, the revenues of which increase with road use. The tire tax is closely proportional to road wear but has the disadvantage that it tempts road users to travel on worn-out tires.

According to the data given in Table 1, a fuel or tire tax designed to meet total or variable maintenance costs on an unpaved road will cover much more than these costs on paved ones. The coexistence of major paved and unpaved roads in developing countries leads to one of the big difficulties in applying the principle that road users should be required to pay the maintenance costs but not the construction costs of uncongested roads. As long as these roads are unpaved, road users are required to pay substantially toward their costs; but as soon as capital is expended on paving a road (capital that is found from general tax revenues), maintenance costs are reduced, and economic theory suggests that payments by users should suddenly fall. For example, those who hold that only maintenance costs should be charged to users would require their contribution to drop from $4,377 to $2,498 on the paving of a gravel road carrying an ADT of 800 vehicles (Table 1); and those who hold that only variable maintenance costs should be charged must advocate user charges to drop from $3,216 to $176, i.e., that road users should be charged virtually nothing for driving vehicles on uncongested paved roads. There are sound reasons for this: the savings enjoyed by road users are (under competitive conditions) likely to be passed on to other sections of the community; and some roads would not be improved if users were required to pay the full costs. Nevertheless, the proposition conflicts with the common sense of the layman, who will ask why the road user should not be required to contribute to the construction of an asset that brings him substantial savings, savings in vehicle operating costs as well as in road maintenance costs. He may even suggest that a fuel or tire tax that covers maintenance costs on gravel roads and total costs on paved ones is a reasonable compromise to aim for in this imperfect world.

Implicit in the assumption that road users should be required to pay only the costs arising out of road use, and not the capital costs of construction, is the assumption that the construction of roads should be planned and financed by a planning organization, external to the road users, which has the ability to assess national priorities and to expend taxpayers' money accordingly. According to this view, there is no necessary relationship between investment priorities in transport and the amounts that road users are prepared to pay for traveling on uncongested roads. The assumption that administrators in developing countries can get adequate roads built without requiring them to be paid for in full by user charges is crucial, and may not be valid. In the developed countries with relatively sophisticated planning techniques, there is little evidence that the allocation of funds to roads is based on the rational judgment of central planners. To expect developing countries to do better may not always be realistic.

OPTIONS IN COVERING TOTAL COSTS

Should we then rely on the second function of prices, and charge users with a view to meeting the total costs? Such a policy is bound to result in some economic losses because of the underutilization of roads: traffic that can bear only the economic user charge would be frustrated if required to pay more. In the case of uncongested roads there is a conflict between the function of prices to ration road space and their function as a means of providing it; a price that will optimize the use of the road will be too low to cover total costs, and a price that will be high enough to cover total costs will cause the road to be partly wasted. There is no general answer to this dilemma: to determine policy in any particular case one must see the extent to which the charging of total costs will discourage traffic and, on the other hand, the size of the deficit that would result if only the economic user charge is levied.

If deficits are small, they may be covered by annual license fees that would not discourage the use of roads but might discourage the growth of the vehicle population. In some cases it may be found that charging full road costs would have a negligible effect on traffic. For example, calculations made for Indian roads suggest that a tax equal to 12 percent of road transport costs would be sufficient to pay for the whole road system, even at the present low vehicle density. In other cases, the deficit might be made up out of the proceeds of property taxes levied on those who enjoy improved access as a result of the road.

It is unwise to generalize about these matters in view of the lack of data. In order to apply the appropriate economic principles in any particular situation, we need to know a great deal more than we do already about the costs arising out of road provision and use, particularly regarding the effect of different kinds of vehicles on the lives and maintenance costs of both paved and unpaved roads in developing countries.

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An Evaluation of Commuter Transportation Alternatives

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This paper develops a framework to evaluate various solutions that are proposed to eliminate rush-hour congestion. The suggested alternatives are grouped into three categories: price changes, institutional changes, and miscellaneous. Two sets of criteria are used to evaluate the alternatives: economic efficiency and various institutional constraints. It is argued that because of the social costs that are external to individual road users (i.e., congestion, air pollution, and noise costs), economic efficiency can be achieved only when the price paid by road users is equal to the marginal social costs for a given time, direction, mode, and route of travel. It is concluded that, in spite of the wide range of alternatives that are considered, only a pricing scheme that would confront road users with all of the marginal social costs of travel by means of special tolls would satisfy the efficiency criterion and also would be administratively, although not politically, feasible. Failure of a pricing scheme to satisfy the criterion of political feasibility at the present time does not imply that the precepts of welfare economics are irrelevant. Understanding the nature of the efficient solution and focusing on the key relationships suggest more acceptable alternatives that could be expected to improve the level of efficiency (e.g., improved transit service, car pooling, and staggered working hours). It also raises the question whether those concerned with planning and administering transportation systems adequately inform the public of the range of possible alternatives, and of their respective costs and benefits.

•URBAN traffic congestion, particularly commuter traffic congestion, is regarded as a major problem by transportation experts as well as by those who undergo the journey to work. Indeed, many regard it as the transportation problem. Many different disciplines have been brought to bear on this problem, many solutions have been proposed, and almost equally diverse criteria have been suggested (1, 2, 3, 4, 5). The basic purpose of this paper is to illustrate how the tools of economics can assist in analyzing, administering, and planning urban transportation systems. Intended for the transportation engineer, the transportation planner, and students of these sciences, the paper skirts some of the intricacies of economic analysis. Specifically, it evaluates different concepts of optimum or efficiency, presents the case for the economic interpretation, summarizes the economic characteristics of motor vehicle travel, gives a brief explanation of the travel behavior of the individual motorist, suggests how to achieve economic efficiency with respect to motor vehicle travel, presents a framework for evaluating alternatives, applies this framework to a number of proposals, and draws certain conclusions and policy implications.

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THE CONCEPT OF EFFICIENCY

At the risk of trampling on the toes of highway engineers and of appearing only to topple straw men, two concepts of efficiency frequently used in highway planning—design capacity and a benefit-cost ratio greater than unity—will be contrasted with economic efficiency.

Although the term design capacity is not included in the most recent edition of the Highway Capacity Manual (6), the concept is still fundamental to the philosophy of highway planning. As developed in the earlier edition of the manual, it is a rule-of-thumb, or design standard, to determine the investment in additional freeway capacity. The planning goal is to construct a facility that will provide a high level of service approximating "practical capacity," i.e., "...the maximum number of vehicles that can pass a given point on a roadway or in a designated lane during one hour without traffic density being so great as to cause unreasonable delay, hazard, or restrictions on the drivers' freedom to maneuver under the prevailing roadway and traffic conditions" (7, p. 7; emphasis added).

The figure suggested for practical capacity on urban freeways under ideal conditions is about 1,500 vehicles per hour per lane, and corresponds to average speeds of between 45 and 50 mph (7). There is no reference to the value or benefits relative to the costs of providing this level of service. The picture was further confused in the old manual by the term optimum speed, or "the average speed at which traffic must move when the volume is at a maximum (i.e., the volume of about 2,000 vehicles per hour per lane)..." (7, p. 17). Thus, the optimum speed corresponded to possible rather than to practical capacity. Apparently the design capacity would result in average speeds higher than the optimum speed!

An efficiency concept familiar to all government offices that make investment analyses is the benefit-cost (B/C) ratio. As long as this ratio exceeds unity, the benefits exceed the costs, and the particular project (or projects) under question are considered worthwhile. If used with great care, incremental B/C analysis will yield the same results as investment rules that are subject to fewer theoretical objections, e.g., maximum rate of return or maximum net benefits (3). However, the standard engineering practice is to count as benefits anticipated reductions in the costs for vehicle operation, travel time, and accidents (3, 8). Aside from the costs that are omitted and the implicit assumption that additional capacity will have no effect on the volume of traffic, there are serious inadequacies in the concept and the measurement of benefits. It is conceivable that highway projects (or programs) A and B might yield identical rates of returns, and identical figures for net benefits, and yet people might place a much higher value on B than on A. Or the calculations might lead to the conclusion that A was more efficient than B when consumer preferences, had there been a market, would have ranked B higher than A.

In the absence of specific information from highway economists concerning how different people value trips for different purposes by different modes at different time periods, highway engineers can be forgiven if they use reductions in costs as a proxy for how much people value these services as indicated by willingness to pay. In view of recent developments in econometric model building, computer technology, and the quantities of travel data collected in the urban transportation studies, transportation economists may justifiably be accused of negligence if they do not exert greater efforts in the future to provide transportation planners with better information concerning the demand for travel. [In order to facilitate the evaluation of alternative transportation policies and to forecast future travel demand, the U. S. Department of Transportation is attempting to construct structural models to analyze the demand for the following transportation services: urban passenger travel, urban goods movement, intercity passenger travel, and intercity goods movements. Examples of research performed under private contract are given in Studies in Travel Demand, and An Evaluation of Free Transit Service (10, 11).]

It has been more than 35 years since Frank Knight expressed concern over definitions of economics as broad as "the science of rational activity," and cautioned economists not to attempt to expand their science to encompass all human behavior (9).

Economists may have taken his admonition too literally because, in terms of both absolute and relative effort, the profession did not concern itself very much with transportation until the middle or late 1950's. Certainly Knight would not have recommended that his colleagues abstain to the degree that they have. In fact, he stated: "There is a common misconception that it is possible to measure or discuss efficiency in purely physical terms. The first principles of physics or engineering science teach us that this is not true, and the term efficiency involves the idea of value, and some measure of value as well" (9, p. 7).

The concept of optimum or efficiency in normative or welfare economics is the one that is best suited for planning and administering transportation systems. The emphasis should not be on constructing a design-hour capacity to provide a certain level of service during all but a stated number of hours during the year or to relieve congestion, but rather on choosing among transportation alternatives so that the greatest amount of satisfaction will result. Transportation decisions—whether by commuters or by the federal government—involve choices among alternatives and require the consumption of resources that are scarce in comparison to the wants that the resources could be used to satisfy. Because there are different benefits and costs associated with each alternative, the appropriate goal should be to choose the alternative (or combination of alternatives) that would produce the greatest difference between total social benefits and total social costs, i.e., to maximize net social benefits. Linking the concept and the measurement of benefits with willingness to pay for the services recognizes the different intensities of people's desires, and allows less opportunity for benefit estimates to be biased by arbitrary judgments. Using the economic concept of cost, i.e., opportunity cost, gives explicit recognition to other opportunities that are sacrificed to provide the service. For motor vehicle travel, then, an optimum or efficient solution would be the number of motor vehicle trips per time period that would result in the largest net social benefits.

Even for all lines of activity (i.e., for an entire economy), if certain assumptions are granted, a sufficient condition to maximize net social benefits is to expand output until everywhere prices are equal to short-run marginal social costs. Then, regardless of where spent, the last dollar of consumer expenditure gives rise to an identical increase in satisfaction, and resources have been allocated in their most efficient manner. [The most important of these assumptions are adequate knowledge, rational behavior, independence of utility functions, and continuous demand and cost functions (e.g., perfect divisibility of the factors of production). Although there is imperfect correspondence between these assumptions and the real world, the degree to which this imperfect correspondence limits the relevance of normative propositions is one of the disputed issues of economics. See Mishan (12) and Ruggles (13, 14) for good explanations and critiques of welfare economics. It follows that prices are equal to short-run marginal social costs because the marginal benefit and marginal cost functions are the first derivatives of the total benefit and total cost functions. Where the first derivatives of the functions are equal (i.e., have the same slopes), the difference between total benefits and total costs is maximized. Beesley and Roth have given a particularly clear exposition of this and other issues pertinent to applying economic analysis to motor vehicle travel (15).]

Even if some goal besides economic efficiency is the principal end, normative economic analysis can assist the transportation analyst to examine various means to achieve the stated ends. To prescribe means, however, requires some knowledge of positive or descriptive economics, which seeks to describe economic behavior and to predict the probable outcomes of alternative courses of action. In price theory, for instance, the behavior of individuals is analyzed in terms of their economic motives as consumers, owners of factors of production, and producers. Transportation economics is a practical application of price theory: the study of the behavior of individuals as they seek to maximize their net benefits in their economic roles as commuters, shoppers, pleasure drivers, haulers, or truck owners. Recent developments in the transportation planning process (e.g., models to simulate the behavior of traffic over networks) may be considered examples of positive economics. The work of such engineer-economists as

Wohl and Martin (16) and Grant and Oglesby (17) illustrates how both normative and positive economics can contribute to transportation analysis and planning.

THE ECONOMIC CHARACTERISTICS OF MOTOR VEHICLE TRAVEL

In the language of microeconomics, the roadway is the fixed factor of production, and the motor vehicle is the variable factor. Combining units of the variable factor with units of the fixed factor produces units of the product, the motor vehicle trip.

Between given origins and destinations, the number of vehicle trips per time period may be assumed to be a function of price. (Although other variables besides price affect the number of trips, e.g., family income and trip purpose, they are assumed to remain constant in order to concentrate on the effects of price changes.) The price that road users pay consists of (a) explicit costs (vehicle ownership and operating costs); (b) implicit costs (odors, noise, effort, tension, and risk); (c) time costs; (d) user charges (taxes on fuel, oil, and tires, tolls, automobile excise taxes, and annual license and registration fees); and (e) parking fees.

These components of trip price are perceived differently by different individuals. People assign different values to odors, noise, effort, frustration, discomfort, and tension. Insurance premiums often depend on whether vehicles are used for commuting. Greater or smaller proportions of automobile excise taxes, annual license and registration fees, and capital costs may be assigned to the journey to work, depending on the purpose for which the vehicle was purchased. Thus the price that individuals perceive will depend on the items that they consider as well as the monetary values they attach to them. [Lansing and Hendricks have concluded that most drivers misperceive their operating costs and that frequently costs are not a serious consideration in the choice of mode (18). However, Lisco's results suggest almost the opposite with respect to travel time (19).]

The costs of motor vehicle travel are the opportunity costs of the resources used, i.e., the values placed on the goods and services sacrificed to provide for the movement and parking of vehicles. These costs may be analyzed in terms of (a) the short-run costs resulting from the use of the physical plant and (b) the long-run costs, which include all the short-run costs plus the costs necessary to provide and to maintain the plant (see Table 1). (The short-run and the long-run are economic time periods. The former refers to the period of time during which the quantities of certain resources or productive factors, i.e., capacity, cannot be altered, and certain costs are invariant with respect to output. For motor vehicle travel, the physical structures are the fixed factors, and depreciation, interest, and administration are among the fixed costs. The long-run is the period of time during which output can be changed by increasing capacity. In the long-run, there are no fixed factors from the point of view of the highway authority, with the possible exception of the quantity of land within a designated area. Effective capacity sometimes can be increased by traffic engineering in a matter of days, or hours, but increasing physical capacity by constructing new facilities requires several years.) Because certain costs that are external to the decision-maker are fundamental to an efficient solution, these external costs must be described briefly.

1. The short-run congestion costs have been dealt with at some length (8, 20, 21, 22, 23). After a certain traffic density has been reached, additional vehicles cause delays, decrease average speeds, and increase travel times. Consequently, they impose costs on the stream of traffic above and beyond the costs that the drivers perceive, because the increase in the total costs to all users of the road exceeds the increase in the costs to the additional drivers. Thus, although the vehicle operating, travel time, and risk costs are largely internal to road users as a group, the congestion costs are external to individual road users.
2. The air pollution and noise costs have received increasing attention by the public but relatively little attention in the highway research literature. Perhaps the reason for this negligence is that these costs are borne by the community at large and are mostly external to highway users, unless automobile exhaust particles and a thermal inversion combine to sharply reduce driver visibility.

TABLE 1

MOTOR VEHICLE TRAVEL COSTS

Description of Costs	Type of Cost in Terms of Time Period[a]
Costs of providing roads:	
Fixed maintenance costs (repairs necessary because of weathering and the passage of time)	L-R
Administrative costs (administering highway program)	L-R
Right-of-way cost (opportunity cost of the land used for ROW or present worth of expected future rents that the land would have earned in alternative uses)[b]	L-R
Construction costs (labor, material, and equipment necessary to convert a ROW to a street or highway)	L-R
Interest on capital (opportunity cost of assets tied up in the street or highway)[c]	L-R
Neighborhood and business disruption and dislocation costs (for those forced to move who were not fully compensated in the past but to whom the 1968 Highway Act increases the compensation)	L-R
Costs of traveling on roads:	
Private costs (borne by those who make trips or on whose behalf trips are made, e.g., truck owners)	
Explicit costs (out-of-pocket costs of owning and operating an automobile, e.g., costs for fuel and maintenance)	S-R, L-R
Implicit costs (effort, tension, annoyance, risk, noise)	S-R, L-R
Travel time costs	S-R, L-R
Congestion costs	S-R, L-R
Community costs	
External costs of road use (noise, air pollution, and risk to pedestrians)	S-R, L-R
Highway operating costs, including variable maintenance costs (e.g., repairing damage to road surface caused by traffic) and traffic control costs (e.g., salaries of police who are assigned to traffic detail)	S-R, L-R
Costs resulting from presence of roads:	
Aesthetic losses (of visual amenities, particularly as a result of freeways, e.g., the elevated Embarcadaro Freeway in San Francisco that obstructs the view of the historic Ferry Building)	L-R
Reduction in access (necessity to take indirect routes in order to pass over or under a freeway)	L-R

[a] L-R is the long-run, or a period of time of sufficient duration to construct additional streets or highways, and S-R is the short-run, or a period of time during which the street and highway network cannot be expanded.

[b] Winch suggests using the capitalized cost of the right-of-way in order to avoid problems of property taxation (8, p. 16).

[c] This cost is included in the discount rate when calculating present worth.

3. The third group of costs consists of the public costs associated with the physical plant that provides for the movement and parking of vehicles. The extent to which these costs are external to individual drivers depends on (a) the payments the individual is required to make (e.g., fuel taxes and license fees), (b) the type of facilities that the driver ordinarily uses, and (c) the basis for allocating costs. On some rural highways, user charges (or the fuel tax component alone) exceed the average and marginal costs of providing the road, especially if costs are allocated on the basis of average daily traffic. On the other hand, commuters who live in suburban areas travel several miles on freeways and park free or at nominal rates on city streets or in garages provided by the employer. They frequently pay only a fraction of the costs of providing the facilities, particularly if the facilities were constructed primarily for commuters and if the bulk of the costs are allocated to this group (2).

A consequence of external costs is that often a larger than optimum number of trips are taken because the number of trips will be determined by the intersection of the demand function with the average private cost function rather than with the marginal social cost function (see Appendix). It should be pointed out that only short-run costs, i.e., costs that vary with the number of trips, are relevant for short-run price-output decisions. Because, by definition, fixed costs are "sunk" during the short-run, there are no opportunity costs resulting from using a road until congestion occurs, i.e., until short-run marginal social costs exceed short-run average private costs, if variable maintenance and air pollution and noise costs are ignored.

THE ECONOMIST'S SOLUTION

In his Wealth of Nations published in 1776, Adam Smith claimed that, in an economy of small shopkeepers, firms would produce the goods consumers want most, and that competition among sellers would drive down prices to the lowest level consistent with a normal rate of return. So great was Smith's confidence in the market that in his most famous passage he claimed: "... every individual ... is led by an invisible hand to promote an end which was no part of his intention...," i.e., to reconcile his own self-interest with the best interests of society (24 Vol. I, p. 423).

The case for the market is not weakened by the fact that equilibrium traffic flows more often than not are characterized by equality between price and short-run average private cost rather than by equality between price and short-run marginal social cost. Implicit in Smith's claim for the invisible hand is the assumption that there are no external costs. It is the presence of these external costs that has led contemporary economists to conclude that the most logical way to correct inefficiencies in motor vehicle travel is (a) to create a market where none presently exists, and (b) to sell the service at a price that reflects the external as well as the internal costs of motor vehicle travel.

Pigou (25) suggested this approach for congested roads almost half a century ago, i.e., to charge a toll equal to the difference between short-run average private costs and short-run marginal social costs at the volume where the demand function intersects the latter (see Appendix).

In the long-run, capacity would be increased or decreased in response to shifts in demand. To use Walters' (5) example, if road capacity could be manipulated like putty, then (a) capacity would be increased if $P = SRMC > LRMC$, (b) capacity would be decreased if $P = SRMC < LRMC$, and (c) capacity would be optimal and in long-run equilibrium when $P = SRMC = LRMC$, where P, SRMC, and LRMC represent price, short-run marginal social cost, and long-run marginal social cost respectively. The fact that freeway lanes come in discrete widths of 12 ft complicates the picture but does not invalidate the principle. (The point is valid because of the very size of urban freeway networks. An additional lane would not be a small relative change in the capacity of a freeway, but it might be a relatively small increment for a network.)

For an urban transportation system, the purpose of road pricing would be to generate price signals and incentives that would direct resources into their most efficient uses. At any point in time, efficient prices would induce and assist people to make optimal choices regarding time, direction, route, distance, and mode of travel. Over a longer time frame, optimum prices would also assist them in choosing residential location and work sites, assist firms in choosing business locations, and assist transportation planners in providing the optimum mix of transportation alternatives. However, socially optimum choices apparently cannot be made without a market to capture the relevant social costs. At present, no highway (or street) market exists except on toll facilities, where the charges are set to recover the capital costs and not to promote economic efficiency. In practice, tolls usually are removed when the original costs of the facility have been fully amortized. Frequently, this is when tolls are needed most for economic efficiency.

THE ANALYTICAL FRAMEWORK

The Criteria for Evaluating Alternatives

In urban transportation planning, the stated goals become yardsticks or norms for evaluating and for ranking alternatives. Although economic efficiency frequently is mentioned as one of the goals, it is usually only one of several goals. Depending on the priorities assigned to the goals, different rankings of the alternatives result. Regardless of the ranking, the alternatives must all meet certain conditions before they can be accepted. For simplicity, the goals and the requirements most common to the urban transportation planning process will here be classified in two categories: economic efficiency and other criteria, which may be regarded as institutional constraints.

Economic Efficiency—The optimum or efficient flow of traffic is that which will maximize the net social benefits in the sense described earlier. If it is assumed that there are no travel benefits external to road users (a reasonable assumption in the case of commuter travel, particularly on freeways), a necessary condition to achieve economic efficiency is that, with respect to route, direction, distance, and time of travel, the equilibrium flow of traffic must correspond to the intersection of the demand schedule with the short-run marginal social cost schedule, i.e., P = SRMC. However, it will not be assumed that a toll, the solution recommended by Pigou, is necessary to achieve the optimum flow (25). Nonpricing solutions will not, ipso facto, be ruled inefficient.

Institutional Constraints—

Break Even—According to one school of thought, the correct principle for determining public utility rates is to set them at levels that will just cover all costs of operation. An important part of the argument is that only if a project can pay for itself can there be absolute assurance that it is worthwhile. Because most public utilities manipulate their rate structures to cover operating (i.e., short-run variable) costs plus some "fair" rate of return on capital, this principle is sometimes called the self-liquidating or public-utility approach (3). In practice, it means setting prices to cover long-run average total costs.

Administrative Feasibility—A proposal must be capable of implementation in order for it to be an alternative. There may be organizational as well as technological barriers that must be overcome before a solution can be implemented. Both types of constraints will be discussed in the evaluation of the alternatives.

Political Feasibility—Even if a proposal can be implemented, it may not be acceptable to the community. Ten years ago, Professor Vickrey suggested a sophisticated electronic surveillance and data processing system for road pricing at the Hearings before the U. S. Congress Joint Committee on Washington Metropolitan Problems. When asked by the chairman whether he had ever "tried this out for audience reactions," he stated: "I will tell you of the audience reaction I got when I proposed essentially the same thing for the New York City subways. The audience reaction was adverse. I will say that while this makes sense to the economists, it seems to be politically, I must confess at the moment, somewhat unpalatable" (26, p. 464).

Equity—The literature of public enterprise economics abounds with different concepts of equity. Kuhn suggests that it may be interpreted as "cost charging" or "charging the same price for everybody" (3). Neutze and Mohring interpret it to mean charging prices that are equal to benefits received (27, 28). Mohring has demonstrated that this interpretation is implied from the wording of Section 210 of the Highway Revenue Act of 1956 (28, p. 57). However, he points out that equity (according to this interpretation) is not an operational concept because individuals who pay the same prices for a service may not enjoy the same benefits from it. (The concept of equity cannot be divorced from the distribution of income. The graduated income tax indicates that the American public considers a more equal distribution of income more equitable than a less even distribution. However, the fact that, in contrast to communist economies, we still rely primarily on the market to determine the income distribution suggests that (a) we are basically satisfied with the distribution resulting from the market, (b) we have been unable to determine just what constitutes an equitable distribution, or (c) we are afraid that greater equality would impair incentives.)

Community Goals—Urban transportation plans, and comprehensive regional development plans, usually identify a number of different ends that include the following: (a) community values, "... certain irreducibles which form the basic desires and drives governing our behavior," e.g., the desire for survival and for such basic needs as to have order, to have security, and to belong (29, p. 135); (b) goals, "... generalized statements which broadly relate the physical environment to values but to which ... no test for fulfillment may readily be applied," e.g., the provision of equal opportunity for all members of a community (29, p. 135); and (c) certain objectives, "... a specific statement which is the outgrowth of a goal, and which is truly attainable because of its reference to the physical world," e.g., the provision of a transportation system that would provide travel times from all homes in the community to the central business district in 30 min or less (29, p. 136).

Some of these ends, particularly the goals and values as just defined, are "high level abstractions" for which "no test for fulfillment may readily be applied" (29, p. 135); an example is the "provision of ample land and facilities for the economic growth of the region" (30, p. 12). The goals are not always mutually compatible, and most often the priorities are not clearly set forth.

The Alternatives

The alternatives are grouped in three categories: price changes, institutional changes, and miscellaneous. In order to emphasize that some of the alternatives involve rather long-time horizons (several years in the case of rail transit systems or freeways), the alternatives are further divided into short-run and long-run alternatives.

The category of price changes includes all alternatives that change the ratios at which peak automobile trips exchange for other trips, for example, bus transit trips during the peak periods or automobile trips during off-peak periods. As well as marginal-cost pricing and reduced transit fares, this category also includes improved transit service at given fares.

An institution has been defined as "... a significant and persistent element ... in the life of a culture that centers on a fundamental human need ... ; a custom that is ... widely sanctioned or tolerated ..." (31, p. 1171). Given the propensity of the American commuter to correlate status with automobile size and cost, a wholesale switch by automobile commuters to smaller, quieter, less powerful vehicles would appear to constitute an institutional change.

Miscellaneous alternatives include all those that do not fit conveniently into one of the other categories and include applying traffic engineering techniques or permitting congestion to build up (i.e., doing nothing).

The Procedure

The various alternatives are examined in the context of a metropolitan area where the automobile is the dominant mode. It is assumed that the marginal social costs exceed the average private costs of travel on the more important highways and streets during the hours of travel to and from work. The analysis is within a partial equilibrium framework. Unless otherwise stated, it is assumed that on other modes and in other sectors of the economy, price equals short-run marginal social costs. This assumption simplifies the argument, but this condition is not a prerequisite for improving economic efficiency (32, 33).

In cases where there is limited experience with the alternative being examined, the examples and the data should be regarded as illustrative rather than typical. The conclusions regarding economic efficiency are based largely on an analysis of the economic forces underlying each situation. Other analysts might reach different conclusions about certain of the alternatives, particularly with respect to administrative or political feasiblity. Because the criteria of equity and community goals are not operational, no attempt is made to judge the alternatives on these grounds. Instead, the reader is invited to specify the criteria and to evaluate the alternatives himself.

THE EXAMINATION OF ALTERNATIVES

Short-Run Alternatives

Price Changes—

1. Make Compensating Payments—Economic theory suggests that one way to achieve an optimal number of trips during the time period in question would be for one group of users to compensate or bribe another group not to use a particular route (or routes) during that time period. As explained by Vickrey: "... if it were possible to select, from among those who would be a part of the peak traffic if left to their own devices, those who have alternatives that they regard as not very much inferior to the use of the

congested facility, and to offer them a bonus for shifting to these alternatives, it might be possible to eliminate the queuing by paying a bonus . . ." (46, p. 126).

A voluntary exchange arrangement would require no coercion and should be politically acceptable. No one would be made worse off, and consequently most popular notions of equity would be satisfied. The fact that we do not have this arrangement today reflects the only problem: It is not administratively feasible, because compensation payments to reduce the air pollution and noise costs would have to be collected from the rest of the community. It is difficult to improve on the assessment made by Professor Vickrey in personal correspondence with the author:

> It is not only variations in the value of time to the drivers but, even more to the point, variations in the relative acceptability of the alternatives that make it impossible to use the "bonus" approach. Even given a costless mechanism of paying the bonuses, it is still likely to be impossible to determine the persons to whom they should be paid, on the basis of any objective criteria, without paying bonuses to those who would not have used the bottleneck even in the absence of the bonus payment, or who would use it only because of the reduction of congestion produced by the bonus.

2. Use Marginal-Cost Pricing—The philosophy of marginal-cost pricing was summarized earlier, and a more detailed analysis is presented in the Appendix. Briefly stated, a toll equal to the difference between the short-run marginal social cost and short-run average private cost is a sufficient, but perhaps not a necessary, condition to achieve a volume that is optimum from the point of view of maximizing the net benefits from the use of the road.

Pigou suggested this approach almost half a century ago (25); however, the pricing of urban motor vehicle travel on particular routes on the basis of marginal cost has not been feasible until comparatively recently. In a recent study, the British Ministry of Transport described and evaluated a number of techniques and specified the following as the minimum requirements for a road-pricing system: (a) charges should be closely related to use and simple to understand; (b) prices should be stable and ascertainable; (c) payment in advance should be possible; (d) users must regard the system as "fair"; and (e) equipment must have a high degree of reliability, and should be reasonably free of unintentional as well as deliberate fraud and evasion (1, p. 7).

A description of the various alternatives is not possible in this paper. However one alternative that should be given serious consideration is PULSE (Public Urban Locator System), which would use triangulation to follow the movements of vehicles (47). A pair of transmitters would send out up to 10,000 different signals per second, and transponders attached to motor vehicles would return the signals. The system is reported to be capable of determining within a radius of 50 ft the location of individual vehicles and of following their movements. The system is now being studied by the Urban Mass Transit Administration for use in conjunction with demand-activitated (dial-a-bus) rapid transit. In April 1969, the U. S. Department of Transportation granted $140,000 to Syracuse, New York, as the first element of a program to develop improved command and control communications in urban transportation. The project will test the feasibility of using a system such as PULSE to communicate with and to control public vehicles, particularly buses and police cars. If a system with a large capacity were chosen, private vehicles could be brought into it at a later date.

A principal investigator in the research underlying PULSE estimated the cost of a PULSE system for a city that has 2 million vehicles and that covers an area 50 miles in diameter to be as follows: transmitters (14 at $0.4 million each)—$5.6 million; factory-installed transponders (2 million at $40 each)—$80.0 million; and central data processing center where the information would be processed, recorded, and totaled so that a bill could be sent to each vehicle owner every month—$2.5 million.

This would average a little over $44 per vehicle. If the transponders were installed after the vehicles left the factory, the average cost per vehicle would be about $100. Present trends in electronic and computer technology might reduce these costs sharply during the next five to ten years. Less elaborate systems such as KarTrak (Sylvania Electric's optical scanning automatic railroad car identification system) should also be considered; Sylvania advertises that the cost of installing the reflective labels on the railroad cars is only $1.50 per car.

On the basis of this research, it appears that it would be administratively feasible to charge road users an optimal set of tolls that would reflect the short-run marginal social costs of trips. [However, this presupposes better knowledge of the demand for travel than we now have, although recent studies, which have produced rough estimates of the demand for travel, are grounds for some optimism (10, 11). The implementation of a pricing scheme would provide specific information that would assist in estimating demand functions. There probably never will be enough reliable data on travel demand. Roth suggests that this probably would not be a serious barrier to implementing a marginal-cost pricing scheme. Beginning with an observed volume-cost relationship (i.e., a point on the short-run average cost curve), he demonstrates that the slopes of demand functions passing through this point can vary rather widely without affecting the optimum toll or benefits proportionately (48).] Thus the prices of trips would vary according to time, direction, mode, route, and distance of travel. The capital and the operating costs of the equipment would in most applications absorb only a small part of the toll revenue and thereby leave a substantial surplus. This alternative, however, is probably not politically feasible at this time.

3. Increase Parking Rates—Substantially higher parking rates would increase the price of automobile trips and reduce the number of trips demanded. Individuals who are willing to pay the higher fees would have an easier time finding a place to park, and this alone might reduce congestion. For maximum efficiency, rates should vary according to location and time of day. With this in mind, Vickrey has made several suggestions concerning how the design and capabilities of parking meters might be altered in order to make more efficient use of on-street parking spaces (49).

Comparatively little research has been done on the elasticity of demand for parking space. Roth found that in England the elasticity was rather low for most parkers (less than -0.6) and concluded: "A parking policy based on higher charges...is likely to lead to a change in the type of parker rather than to a change in the volume of parking. Short-term parkers would replace long-term ones; shoppers would replace people at work" (50, p. 126). Roth concludes that it is not feasible to deal with traffic congestion by means of a surcharge on parking fees.

Data published by the Road Research Laboratory appear to substantiate Roth's predictions. In April 1965, on-street parking rates in central London were raised from 6d (six pence, or about 7 cents in 1965) to 1s (one shilling, or 12 pence) in some areas, and from 6d to 2s in other areas. The Road Research Laboratory carried out "park-and-visit" tests between 9:30 a. m. and 4:30 p. m. on weekdays during February and March, and again in June and July. The results were as follows: "At eleven addresses where the meter charges were doubled, the time required to search for a vacant meter was reduced by 60 percent, and the time required for maneuvering the car at the meter bay and walking to and from the addresses visited decreased by 16 and 23 percent respectively. At fifteen addresses where the meter charges were quadrupled, the time required to search decreased by 83 percent and the car-maneuvering and walking times decreased by 34 and 5 percent respectively" (51, p. 5). Speed tests on selected streets showed no important change in average traffic speed after the increase in rates.

However, Kain suggests that traffic volumes would be reduced by a more ambitious program that would involve two alternative bases for parking charges in central areas. "The first is the cost of providing highway capacity into central areas and should apply to the all-day parker who generally will use the city streets during the peak hours. The second should apply to the short-term parkers who generally will not use the streets during peak periods. He should be charged only the cost of providing parking spaces" (36, p. 12).

Higher parking charges probably would not be as efficient an alternative as marginal-cost pricing because (a) the charges would bear no relation to the distance traveled nor to the type of roads used; (b) if congestion in the central city were reduced, additional through traffic might be attracted; and (c) less congestion might increase the amount of goods traffic carried by truck relative to rail. Thus some trips that did not contribute to congestion would be discouraged, and the very process of reducing congestion in the central city might attract non-parking traffic. Restrictions would have to be imposed on the construction of parking garages for this scheme to be effective, because higher on-street parking rates would increase the profitability of constructing privately operated off-street parking facilities. However, rather rough estimates suggest that, for London, the effects of higher parking fees on average speeds and on net benefits are about 40 percent of what is claimed for a pricing solution (1, p. 60).

In order to make more efficient use of a scarce resource, urban land, a very strong case can be made for instituting a system of parking fees that would vary according to time of day and location. A truly optimum scheme, however, is one that embraces both road pricing and parking fees and one in which "...the allocation rule (for road space) would be that the number of street parking spaces should be increased to the point at which parking charges paid by street parkers just equalled the congestion charges paid by moving traffic" (52, pp. 32-33).

To summarize: Substantially higher parking fees, especially for commuters, would produce a more efficient number of trips, but probably not an optimum. This alternative would yield surplus revenue (at least in the short-run) and appears to be administratively feasible. The fact that parking rates in downtown Manhattan have been increased to 25 cents an hour suggests that this alternative may be politically feasible on a much more ambitious scale. Arthur E. Kane, Chief of the Bureau of Parking, of the City of New York's Department of Traffic wrote the author that "...occupancy in mid-Manhattan has not changed appreciably since we increased the rates from 10 cents to 25 cents but our turnover has increased 53 percent. The reason that occupancy is still close to 100 percent is that we have an acute shortage of off-street space in mid-Manhattan and the demand for short-term parking far exceeds the supply of metered spaces (at the rate of 25 cents per hour)."

4. Apply Zone Pricing—A rather imaginative zone-pricing scheme has been suggested by the British Ministry of Transport and by A. A. Walters (1, 5). With this scheme, the metropolitan area would be divided into a series of concentric zones, with the CBD constituting the center. Starting from the periphery, the zones, in ascending order of the price of licenses, might be designated blue, brown, pink, green, and purple. Drivers with blue permits displayed on their windshields would be limited to blue areas; drivers with pink permits would be restricted to blue, brown, and pink areas; and drivers with purple permits would be free to drive in all areas.

A number of variants to this scheme could make it quite flexible in practice. The permits could be required during the peak hours or during the period beginning with the morning rush and ending with the evening rush. A given number could be distributed to service stations to be sold on a competitive basis at prices that just cleared the market. The permits could be sold on an annual, monthly, weekly, or daily basis. They could be transferable among vehicles to permit additional drivers to use zoned areas without adding to congestion.

Such a scheme has several drawbacks. The zone boundaries would, to a large degree, be arbitrary. The relationship of the fees to cost per vehicle-mile might be weak, because it would be impossible to differentiate simultaneously with respect to time, route, direction, and distance traveled within a particular zone. Congestion might develop around the zone boundaries. Hence, although the scheme would reduce congestion and result in more efficient use of certain streets and highways, it would not be an optimum solution. However, a scheme that consisted of a single uniform toll zone (e.g., the central city or the CBD) could be relatively simple to administer and could provide a laboratory to test the principle of pricing scarce road space during certain hours of the day.

5. Increase Fuel Taxes—The zone-pricing system could be used as the basis for a scheme that would relate fuel taxes to the degree of congestion. A refined scheme might involve several different rates for several different zones in a large metropolis or megalopolis, with the differential between the adjacent zones sufficiently low to discourage fuel-fetching journeys. A cruder scheme might simply differentiate between urban and rural areas and tax fuel sold in the urban area at much higher rates than that sold in the rural areas (1, 5).

If fuel tax rates are substantially increased, this approach could be expected to have the following effects: reduction in the total number of vehicles owned, reduction in average use by owners, increased use of transit, and substitution of small economy cars for larger vehicles. The total effect would be to reduce peak-hour (and total) volumes. However, this appears to be even less efficient than the zone-pricing scheme as an instrument to relate travel to marginal social cost per vehicle-mile, particularly because travel on uncongested roads and off peak would be penalized unnecessarily.

Fuel-fetching journeys would reduce the effectiveness of this scheme and would be a waste of resources. Again, the boundary lines might prove to be quite arbitrary, and the scheme would tend to discriminate in favor of long-haul as opposed to short-haul traffic. Its political feasibility appears questionable, but, if adopted, it would be a source of revenue. The British Ministry of Transport rejected this alternative as being impractical (1).

6. Increase Automobile Excise Taxes—Substantially higher excise tax rates (e.g., 25 percent or more instead of the present 7 percent) would make it more expensive to buy a car and hence reduce vehicle ownership and total travel. However, it might have little effect on peak-hour travel because it would not affect the driver's short-run variable costs. For reasons cited by Walters (5), its overall effect on economic efficiency might be negative, and the redistribution effects probably would not be acceptable. Although simple to administer, this alternative probably would prove too unpopular to adopt.

7. Reduce Transit Fares—If transit service characteristics and the price of automobile travel remain unchanged, reducing transit fares would lower the price of transit relative to automobile trips. Such a price change could be expected to result in an increase in the number of transit trips and a reduction in the demand for automobile trips, if individuals have a choice of mode. Particularly if there are empty transit seats or idle equipment during the rush hours, and if automobile users are being subsidized (or if the automobile subsidy per passenger exceeds the transit subsidv per passenger), a strong case can be made for subsidizing transit. [A subsidy may be said to occur when the price paid for a good or service is less than the short-run marginal social cost of providing the good or service. Questions such as whether urban automobile travel—or automobile travel in general—is subsidized are the subject of considerable debate (34). Such discussions miss the crux of the economic problem, however, and that is whether individuals are confronted with prices that reflect the marginal social cost of the particular services that the users are said to "demand." If prices do reflect all of the social costs, then individuals have the necessary information to make decisions that will be optimal from the point of view of the community.] If transit fares were to be adjusted to make the differential in price agree with the differential in marginal social cost relative to automobile commuting under current conditions, a large minus fare (i.e., the payment of a bonus to transit riders) would be called for in congested areas, particularly where both use the same right-of-way. Because the price ratios of other services vis-á-vis transit also would be affected, this approach would be less efficient than that of pricing both automobile and transit trips at prices that approximate marginal social costs. However, as long as the sensitivity of the demand for other services with respect to the price of transit trips is small (which would appear to be the case), then reducing the price of transit travel would, a priori, reduce automobile congestion and contribute to a more efficient utilization of road space. Because transit is only one of many municipal services that compete for local revenues, finding funds to cover deficits would be a perennial problem.

Charles River Associates recently completed a study for the U. S. Department of Transportation to estimate the effects of free transit in the Boston area. Among their conclusions were the following: (a) free transit would reduce automobile work trips only by 6 or 7 percent and would have even a smaller impact on nonwork, off-peak trips; (b) the fare elasticity of demand for transit travel is only about 0.17 percent; and (c) the cross elasticity of demand for automobile travel with respect to transit fares is only 0.138 for work trips (11, pp. 7, 13). [Because the trend in transit prices has been upward since World War II, empirical evidence of changes in ridership accompanying fare reductions is scanty. In 1961 the Los Angeles Metropolitan Transit Authority reduced off-peak fares from 22.5 cents to 15 cents per ride for senior citizens. Figured on a 12-month basis, 862,250 former peak-hour riders shifted to off-peak hours to take advantage of the lower fares (53, pp. 77-78). However, in a demonstration project in which commuter-train fares in Boston were reduced 24 to 30 percent, peak-hour riding increased only 2 percent (11, p. 53). Pignataro (54) gives additional examples. Unfortunately, it is seldom possible to compute demand elasticities from the information given.] It was estimated that with free transit there would be a saving of about $2 million as a result of not having to pay attendants to collect fares in subway stations, but savings of this magnitude should not be expected on a predominantly bus-transit system. Experience suggests transit subsidies are both administratively and politically feasible. What is not certain is whether large reductions in transit fares, and particularly free transit, is politically feasible.

8. Improve Transit Service—A broad interpretation of transit service would include the following: (a) travel time, including walking at both ends of the journey, time spent on the collection, line-haul, and distribution phases of the trip, and schedule delay [". . .additional time that may be incurred because the arrival time allowed by the transit schedule may differ from the traveler's preferred arrival time" (11, p. 32)]; (b) aesthetic appeal of vehicles and terminals (appearances, noise, and odors); and (c) quality of the ride (size and comfort of seats, ease of entry and exit, lighting, and heating and air conditioning).

Travel time was described earlier as one of the components of both the price people are willing to pay and the cost of resources consumed for trips. Careful analysis should be made to determine the weights different groups of riders assign to different segments of the trip. Particularly in inclement weather, transit riders can be expected to assign higher costs to the walking and waiting phases of the journey than to the line-haul, collection, and distribution phases. To date, no satisfactory way has been devised to reduce to a common demoninator and to estimate the effects on the demand for transit trips of improvements in transit service, particularly (b) and (c) above. In principle, the effect would be the same as a reduction of transit fares with service characteristics held constant, i.e., to increase the number of transit trips purchased and to decrease the demand for automobile trips.

But this will not necessarily lead to lower traffic volumes and higher speeds on a given route during the peak hour for a sustained period of time. Reduction in congestion may encourage more people to drive, attract traffic from other routes, and shorten the duration of the peak. Consequently, the fact that it is difficult to correlate improvements in transit service with reductions in automobile congestion is not surprising, particularly in light of the present pricing structures and the growth in the demand for travel over time. Even so, it remains important, from the standpoint of making the most efficient use of scarce resources, that improvements in transit service may result in fewer total automobile trips and less overall congestion than there would have been without the transit improvements. [The "GO Transit" program of the Government of Ontario added more (and faster) trains during rush hours, bucket seats, and free parking at stations along the eastern and western corridors leading to Toronto. During the initial phase (May 23 to December 31, 1967) average weekday trips increased from 5,600 to 15,800. Interviews revealed that nearly a third of the evening peak riders previously drove cars. It was estimated that, by December 31, about 1,800 automobiles were being left at home because of the program (55).]

Because of the greater flexibility of bus transit as compared to rail, a number of the Urban Mass Transit Administration's demonstration projects have been aimed at making more efficient use of urban street and highway capacity. The success of the subscription bus service in Peoria, Illinois, serves as an example of what can be achieved with imagination. The service extended from December 1964 to March 1966. It was successful enough to cover its total variable costs in 6 months and its total costs (i.e., variable plus fixed costs) in 11 months. For an average fee of $9.90 per month, passengers were able to obtain almost door-to-door service between home and work. On the Premium Special commuter bus, 72 percent of the 542 riders previously had used the automobile. The premium buses operated at an average speed of 16 mph (as compared to 11 mph for other buses), and 68 percent of the passengers were able to leave for work in the morning at the same time or later than when they used their own cars. Moreover, it was found that the fare elasticity of demand was almost unity, indicating enough passengers were willing to pay higher fares for better service to permit fare increases without appreciably reducing total revenue (54, 56).

Many of the conclusions with regard to lower transit fares also apply to improved transit service. Economic efficiency in terms of the use of the road network would be improved, but probably not all transit companies could improve service and break even. Experience suggests that this alternative is both administratively and politically feasible. Beginning in April 1964, the Milwaukee and Suburban Transport Corporation established service from the Mayfair Shopping Center west of Milwaukee to Milwaukee's CBD. Known as the Mayfair Freeway Flyers, the buses travel 9 miles by freeway to the CBD in 22 minutes. Fares were set at 30 cents each way, with a discount for weekly passes. By October 1966, the company was operating ten buses each morning and afternoon. The number of passengers per day had risen from approximately 250 to 900, and the company reported a $12 profit per operating hour for the Mayfair Flyers. A questionnaire revealed that, among the passengers who commuted prior to the inauguration of the Flyers, 43 percent and 10 percent respectively traveled in their own cars or in car pools. Over 50 percent cited as a reason for changing modes the advantages in terms of time, congestion, parking, convenience, and economy (57).

Institutional Change—

9. Shift Travel to Off-Peak Hours—The study by Charles River Associates indicates that as much as 33 percent of the morning peak (7:00 to 9:00 a. m.) to 60 percent of the afternoon peak (4:00 to 6:00 p. m.) in Boston may be nonwork trips (11, p. 160). The pattern is similar in other cities, with the higher figure for the afternoon peak reflecting the greater proportion of shopping trips. Friday afternoon peak volumes are usually the heaviest of the week, partly because of weekend travelers. Vacationers swell all volumes in the summer, but particularly during the afternoon. Local factors also are important. In San Francisco, baseball fans leaving Candlestick Park after the afternoon games and fans bound for the stadium before evening games noticeably swell afternoon peak-hour volumes on the Bayshore Freeway (US 101) and the San Francisco-Oakland Bay Bridge. San Francisco International Airport also is served by the Bayshore Freeway, and the arrival and departure times of planes are such that traffic to and from the airport contributes to peak-hour volumes.

Finally, trucks contribute substantially to peak-hour traffic in some areas. A traffic survey conducted by the Institute of Transportation and Traffic Engineering of the University of California indicated that during the peak 60-min period in the afternoon, approximately 5 percent of the total eastbound traffic on the San Francisco-Oakland Bay Bridge consisted of heavy trucks and truck-trailer combinations (58). If four passenger cars are allowed as equivalent to a heavy truck and six to a truck-trailer combination, then 1,500 passenger cars units (168 × 4 + 138 × 6) were accounted for by the trucks on April 10, 1962. [Four automobiles are equivalent to a heavy truck on highways in rolling terrain (6, p. 104). Because no figure for trailers is given, the author estimated that one trailer is equivalent to two automobiles.] This is about the maximum number of automobiles that a freeway lane can accommodate at a high level of service. It also represents about 20 percent of the eastbound capacity of the Bridge that has five lanes of traffic in each direction.

To state the problem in this manner suggests an alternative: Shift some of the nonwork trips out of the peak hours. Perhaps some trips cannot be shifted, for example, those by school buses and milk delivery trucks. However, the majority of noncommuter, peak-hour travel might be shifted at relatively little inconvenience to those concerned. This certainly would appear to be true for shoppers, weekend skiers, and summer vacationers. Changing the starting times of baseball games by half an hour to an hour would help substantially in many areas. So might minor modifications of airline schedules. Heavy trucks and truck-trailer combinations, which use the Bay Bridge, voluntarily shifted to some extent during the 1953 strike of Key Transit Company.

Any such scheme would involve benefit losses to some. Where pricing is not used, and there is thus no market to permit individuals to express their preferences, decisions concerning who would and who would not be permitted to travel during a particular time span would have to be based on judgment, and any scheme of regulation would be to some extent arbitrary. Probably some excluded users would value the service more than would some of those permitted to use the facilities during the time period in question. The same would be true for some of those affected by changes in the starting times of baseball games and changes in airline schedules. Consequently, an ambitious scheme might not be politically feasible. However, it would be administratively feasible to permit only vehicles displaying permits to use key routes during peak hours or run the risk of having to pay a fine. Even though 100 percent compliance would be impossible to achieve, the author suspects that it would be possible to shift sufficient traffic out of the peak hours to substantially increase net benefits in many urban areas, particularly if a fee were charged for the permit and a crude form of pricing resulted similar to that in alternative 4.

Miscellaneous—

10. Stagger Work Hours—On facilities where peak travel is not spread evenly over the peak period, congestion and delays would be reduced and economic efficiency would be improved if a more even flow of traffic were achieved. In central London, for example, the peak periods are 7:00 to 10:00 a. m. and 4:00 to 7:00 p. m. In 1958, however, a sixth of the workers arrived in the morning and left in the afternoon during the peak 15 min (59, p. 4). Even in Washington, D. C., where about half of the employees work for the U. S. Government, a study conducted in 1963 revealed that although starting times of federal agencies were staggered by 15-min intervals from 7:00 to 9:00 a. m., 5,745 employees reported at 7:45, 27,489 reported at 8:00, but only 11,054 reported at 8:15. Over half (57.4 percent) reported during the 30-min period between 8:30 and 9:00 (60, pp. 9, 11). The 1963 study included a plan to reduce the peak volumes by changing the working hours of federal offices. During the five years that have elapsed since that study, a number of new federal buildings have been constructed, particularly in the southwest area, and another study is now in progress.

The experience in Washington, D. C., and London indicates that the major problem of staggering schemes is that of compliance. The London effort failed to get the cooperation of the transport groups in the six zones in which London was divided. Many workers did not want to be inconvenienced by changing their hours, and merchants were afraid of losing business if they closed their stores earlier. Even in Washington, D. C., which appears to be ideally suited to staggering work hours, the 1963 recommendations were not adopted. The conclusions with respect to shifting travel to off-peak periods (alternative 9) would seem to apply with equal force to staggering travel times within the peak.

11. Encourage Car Pooling—A number of steps could be taken to increase average automobile occupancy. The ITTE traffic survey revealed that in 1961 the percentage of cars traveling in the westbound direction on the San Francisco-Oakland Bay Bridge and carrying only one person during the hours 7:00 to 7:30, 7:30 to 8:00, 8:00 to 8:30, and 8:30 to 9:00 on weekday mornings was 58, 61, 74, and 76 respectively. During those periods, average passenger occupancy was 1.77, 1.65, 1.37, and 1.39 respectively (58). The records of the bridge show that average daily occupancy rose from 1.9 to 2.4 following the outbreak of World War II, and from 1.8 to 1.95 during the Key Transit Company strike in 1953.

Parking space could be restricted or at least provided on more favorable terms to car pools, as it is now done in many federal parking garages. Road and bridge tolls could be correlated inversely with average occupancy, with cars carrying four or more persons permitted to go free. Cars carrying four or more persons also might be given preferential access to freeways and possibly even exclusive freeway lanes. Car pooling could be facilitated in a given area if all commuters interested in automobile travel were given cards to fill out stating whether they desired to be drivers or passengers and specifying their working hours and home and work addresses. The cards could be returned by mail, postpaid, to a data processing center that would match drivers and passengers and notify the drivers of individuals with similar origins, destinations, and work hours who were looking for rides; similarly, it would notify passengers of drivers. The fact that many persons might be drivers or passengers would increase the flexibility of such a scheme. (Federal office buildings in Washington, D. C., employ a simple but effective system that includes a large map of the area, a grid system to identify residential zones, green and red cards for drivers and passengers respectively, and a rack with slots for each zone on the map. Individuals interested in passengers or rides fill out a card and insert it in the appropriate box.) Rates of remuneration could be suggested by the agency coordinating the plan, but left to individual parties to decide. Rates might have to be sufficiently high to cover increased insurance premiums. A variant of this scheme would be to designate certain individuals as franchised operators and let them charge rates sufficiently high to cover the costs of purchasing and operating a station wagon or microbus.

Car pooling is one obvious way to make more efficient use of existing capacity. One current operation is proving that this alternative is both administratively and politically feasible, and perhaps even the basis for a profitable enterprise! Monarch Associates is probably the first federally authorized interstate car pool. The firm owns and operates 20 vehicles that carry about 140 commuters from Rockland County, New York, and Bergen County, New Jersey, to New York City. It obtained its first group of customers by advertising in local newspapers. The firm provides vehicles and arranges pools on the basis of origins, destinations, and working hours. Because one member of each pool drives, there are no explicit wage costs. Operating and maintenance costs, parking charges, insurance premiums, and tolls are paid by the company. The travel times and the charges are below those of the local transit companies. Businessmen commuting from northern Bergen County pay $8.50 a week, while Rockland County commuters pay $9.50. To date, the company has more requests than it has been able to accommodate (61).

12. Apply Traffic Engineering Techniques—A number of techniques may be used to increase the effective capacity of an urban street and highway network. Measures such as intersection control, reversible lanes, one-way streets, access control, and restrictions on parking, stopping, and loading are common practice. Such measures usually have been financed with state and local funds. However, these and more ambitious projects (e.g., street widening) now are eligible for 50 percent federal assistance through the TOPICS program authorized by the Federal-Aid Highway Act of 1969. Changes in the existing network may be made in conjunction with improved transit service (alternative 8) by having exclusive bus lanes and by giving preferential freeway access to buses or car pools. The U. S. Bureau of Public Roads is giving increasing emphasis to such measures to increase the passenger—as compared to the vehicle—capacity of urban highways. As a case in point, Interstate 95 (the Shirley Highway) linking Washington, D. C., with the western edge of Alexandria is to be modified in order to give buses, or possibly buses and car pools, an exclusive lane.

In some urban areas, particularly those on the West Coast, improvements in the existing network have progressed about as far as present technology permits. In Los Angeles, for example, a computer automatically adjusts stoplights according to traffic volumes. A sophisticated computerized system being installed in Toronto has already demonstrated substantial savings in vehicle operating, travel time, and accident costs (86). Homburger and Rainville have suggested that in the future, automated freeways using electronic systems to space and guide cars "...could conceivably permit headways of about 1 second, corresponding to a design flow rate per lane of 3,600 vph..." or almost double present freeway maximum capacity (62, p. 42).

Measures to increase effective capacity result in more efficient use of scarce resources, and generally they may be assumed to increase economic efficiency. Usually such measures meet both the feasibility tests, although attempts to make a particular street one-way or to ban on-street parking during certain hours frequently meet with opposition and occasionally are blocked.

13. Restrict Vehicles—An alternative that is mentioned in the press sometimes is to restrict the movement of vehicles in congested areas such as the CBD (63). Proposals range from allotting permits to selected individuals to banning vehicles from certain areas. Such a scheme could be very costly to administer, particularly in view of the necessity of deciding what is and what is not essential traffic. Without the calibration provided by charging prices, this alternative would provide no guide for investment. To the extent that permits are auctioned or sold, the conclusions of alternative 4 (zone pricing) apply. However, if permits were distributed on any basis besides price, it would be difficult to judge whether, on balance, efficiency had been increased or decreased. Black-market sales of permits might frustrate the scheme, although they might improve economic efficiency if the permits were sold to the highest bidder.

The idea of banning vehicles from certain downtown areas has some precedent. A number of cities have experimented with barring vehicles from certain streets in order to create shoppers' malls. Any effort to ban private vehicles from the downtown area probably would have to be part of a larger plan that provided for public transit within the restricted area. Although congestion within the area would be reduced, it would be difficult to judge whether efficiency had been improved without knowing people's demands for various types of transportation services. Congestion and parking problems almost certainly would result on the periphery of the area. Fences or barricades would make such a scheme administratively feasible, but the fact that it has never been attempted in a large city raises doubts about its political feasibility.

14. Allow Congestion—During a particular time period, the demand for a service may exceed its supply at the existing price. When this occurs, some demands will go unsatisfied; i.e., there will be certain individuals who are willing to pay the price of the service but who will not be able to obtain it during that time period. This situation is rare in well-organized, competitive markets such as stock exchanges, because prices are raised almost instantaneously in response to increases in demand. In cases where prices cannot fluctuate, some other means must be found to ration the output among all those who would buy it at the given price at that point in time. The service is provided on a first-come-first-served basis at barber shops, entrances and exits for major urban arterials during peak hours, and parking garages. After capacity has been reached, queues build up, and people wait in line to receive service. Some individuals become impatient and attempt to find service elsewhere during that time period, or return and try again at a later time period. In contrast to rationing by price or by coupons as was done during World War II for meat, sugar, and gasoline, the process just described may be termed rationing by congestion.

This approach is the simplest way to allocate the existing street and highway network. As a policy for dealing with peak-hour travel, however, it has very little else to commend it. It is efficient only in the sense that for each additional user, the marginal utility of the trip is equal to his own personal marginal (average social) cost. For some individuals, the route, the time of travel, the amount of time spent traveling (within certain limits), and even the trip itself will be marginal. For others, the values attached to travel time and such implicit costs as risk, effort, and tension may be quite high. However, a laissez-faire policy results in those who place the lowest values on these components of price determining the terms of travel both for themselves and for those who place the highest values on these components.

This alternative is currently popular, but there are only two ways it might improve economic efficiency: (a) if the peak is spread over a longer time period so that there is excess capacity during fewer hours of the day; and (b) if alternate routes or modes receive greater use, if there is excess capacity, than they would in the absence of excess demand. Unless the alternatives provide high levels of service and queuing diverts commuters from automobiles to forms of transit that are exempt from the queuing process (these forms usually involve separate rights-of-way for at least some portions of the trips), the net effect probably would not be in the direction of a more efficient utilization of the street and highway plant. However, experience has shown that this alternative is both politically and administratively feasible, at least as a temporary measure when additional capacity is being constructed and when traffic engineering alternatives have been exhausted.

Long-Run Alternatives

Price Changes—

15. Use Marginal-Cost Pricing—The long-run costs are itemized in Table 1. For any existing or future route, the long-run demand for travel consists of (a) existing demand, (b) traffic diverted from other routes, (c) generated traffic (i.e., new trips as a result of improved access), and (d) secular-growth traffic.

If simultaneously P = SRMC = LRMC, then price, output, and capacity are optimal, and long-run as well as short-run equilibrium has been achieved. If the short-run optimum price exceeds the long-run marginal social costs (i.e., if P = SRMC > LRMC), then capacity would be expanded to the level of output that would make the long-run equilibrium consistent with the short-run equilibrium. If the short-run optimum price is less than long-run marginal social cost, worn-out capacity would not be replaced until the level of output and price were again consistent with long-run as well as short-run equilibrium. The analysis can be expanded to include interdependencies with respect to costs and demands on a road network, off-peak as well as peak demands, and interdependencies among time periods. [For suggestions on how to treat these and other relationships, see the contributions by Kraft and Wohl (64), Martin and Wohl (16), Steiner (65), and Winsten, McGuire, and Beckmann (23).] The guide for achieving efficiency in the short-run still applies: The price of travel on any route would include a toll equal to the external costs of travel.

In the absence of specific demand and cost information, it would be impossible to predict whether marginal-cost pricing applied to an urban highway or to an urban street and highway network would produce a surplus, break even, or result in a deficit over time. [For a comparison of the expected cost reductions with the capital costs of additional freeway construction in the Twin Cities Metropolitan Area, see Mohring (66).] It was argued earlier (alternative 2) that this alternative probably could be implemented, but it does not appear to be politically feasible at this time.]

Institutional Change—

16. Reduce Automobile Size—A substitute for increasing peak automobile occupancy (alternative 11) would be to reduce automobile size. Harris has estimated that "if the average new auto were only a foot shorter, and if 4 million a year were destined for city use, about 800 miles of street space would be released" (67, p. 153). If all automobiles, or at least if all those traveling during the commuting hours, were half the size of the most popular Detroit products, a smaller investment in urban freeways would provide service comparable to the levels anticipated in present urban highway plans.

To create some incentive for buying smaller automobiles, Harris suggested that for cars over 180 in. long, an annual fee might be levied at the rate of $1 per in. for lengths between 180 and 185 in., $3 per in. between 185 and 190 in., and $10 per in. for lengths in excess of 195 in. Roy Poulsen has proposed a similar scheme (68). The same approach could also be used to reduce width. The author's own observation is that 180 in. or 15 ft is considerably longer than needed for a vehicle whose sole purpose is the journey to work (the standard Volkswagen is 160 in. long), especially when average peak-hour occupancy always is less than two persons per vehicle. On September 7 and 8, 1968, an automobile exhibit sponsored by the Smithsonian Institution and the U. S. Department of Transportation included prototypes of vehicles designed especially for commuters; many were approximately half the length of most Detroit cars. A study performed for the U. S. Department of Housing and Urban Development describes experiments with other small vehicles (69).

In addition to requiring less street and parking space, small automobiles have another significant advantage: They require a smaller power plant and, consequently, are well suited to electric motors. Electric motors, of course, are pollution free and practically noiseless. The Yardney Electric Corporation claims it has developed a model capable of speeds up to 60 mph and ranges of up to 150 miles between battery charges (70). The major technological barrier appears to be the development of inexpensive, lightweight, dependable batteries capable of providing the sustained power and the performance needed for a commuter vehicle. Current research in electric and hybrid power plants and bold predictions by manufacturers of batteries and by power companies suggest that the technological barriers are surmountable and that progress could be accelerated if more resources were devoted to research. Osaka, Japan, has been converting its buses to battery power, and England already has some 40,000 electric delivery trucks. Ford Motor Company is reported to be ready to test sometime in 1969 a 500-lb sodium-sulfur battery for a small city-car designed by its British affiliate (69, 70, 71). Rowan Industries advertises that the operating costs of its electric vehicle are less than a penny a mile.

There are other difficulties associated with small vehicles: "Even by making all cars very small, the flow-unit areas of roadway would less than double; moreover, to take advantage of the narrower lanes allowed it would be necessary to remake the road system. An additional major disadvantage of small city-cars is the reduced safety afforded passengers in collisions . . ." (69, p. 112). In addition, there might be some increase in the amounts of pollutants discharged to produce electricity. This would depend on the amount of thermal electricity produced, and on the effectiveness of efforts to reduce the omissions of thermal electric plants. Thermal power stations traditionally have used sulphurous fuels that produce sulphur dioxide. Many are now converting to natural gas, and the newer power plants are favoring atomic energy.

The author doubts that the safety question would be serious if all vehicles were small and lightweight, if their maximum speeds were no greater than 50 mph, if they were sturdily constructed, and if they were equipped with lap and shoulder harnesses and devices similar to the Auto-Cepter to protect passengers from the secondary crash. (The Auto-Cepter, developed by Eaton, Yale, and Towne Inc., is a large ballon that inflates in front of a car's occupants within 20 milliseconds of a front-end crash, and provides cushioning against the force of the collision when the vehicle's occupants are hurled forward. The U. S. Department of Transportation is considering making such a device mandatory on all new automobiles.) On balance, there probably would be substantial reductions in the amount of air pollution. Motor vehicles presently account for about 60 percent of the dirt and fumes released into the atmosphere in the United States, and 90 percent in Los Angeles County. They also are responsible for the greater portion of the atmospheric hydrocarbons, carbon monoxide, and nitrogen oxides for the United States as a whole (72).

Battery-powered vehicles are only one alternative. Fuel cells, steam engines, liquefied natural gas, certain changes in the internal combustion engine, and various hybrids also appear capable of providing quieter, cleaner power plants (69). Although replacing present vehicles with much smaller ones would not eliminate peak congestion, it would make much more efficient use of urban streets, highways, and parking areas. It is administratively feasible, but the political acceptability of this alternative appears doubtful at this time.

17. Build New Towns—Because the majority of middle-income Americans apparently want to live in the suburbs, an alternative to moving people to jobs in or near the city is to move the jobs to the suburbs. Although this approach was suggested over 400 years ago by Leonardo Da Vinci, Ebenezer Howard is regarded as the father of the new towns that are being built today. His idea is described in these colorful words by Lewis Mumford:

> He sought to replace the planless over-expansion of the big city with a planned "colonization" to draw off the surplus population. To achieve this, he proposed to build largely self-sufficient communities, limited in size and density of population but big enough to sustain a variety of industries and satisfy the everyday wants of the population. In these towns the land is held and controlled by a public authority. He also made one of the few major contributions to the art of city building since the Stone Age invention of the city wall by suggesting that each of these towns be surrounded by a horizontal wall of agricultural land, or "green belt" (73, p. 23).

New towns presently under construction include Irvine, California; Reston, Virginia; Columbia, Maryland; and the Don Mills Communities on the outskirts of Toronto (74, 75). In theory, they are to be relatively self-contained communities with their own industries, schools, shopping centers, medical facilities, and residential areas. The neighborhoods in the Don Mills Communities are being built around the public schools. In North America, these communities are at least 10 miles from the central city, and in Britain, they are 30 miles from London. In Britain they are connected with each other and with London by rail transit. In Canada they are being built near a railroad and an expressway to give people who commute to Toronto a choice of travel by commuter trains, rail rapid transit, or automobile. Each of the Don Mills Communities is spatially separated from the others by a green belt.

In principle, this alternative would reduce travel costs in two ways. First, because of close proximity to employment, many could walk to work and others could drive or use local transit service. Second, locating the new town on a rail line (as the Don Mills Communities are) allows those who want to commute to the central city to have some alternative besides the automobile.

It is too early to judge the success of new towns in North America. In Britain they failed to curb the growth of London after World War II, as had been hoped. Many Englishmen who can afford to live either in London or in a new town apparently enjoy living in close proximity to the amenities of their capital. In the cases of Reston, Virginia, and Columbia, Maryland, a large proportion of those employed commute (i.e., drive) to Washington, D. C., or to Baltimore. In this respect, the new towns so far are not unlike the "bedroom" communities typical of suburban America. Irvine appears the most likely to achieve the goal of a relatively self-contained community because it is planned around a campus of the University of California.

It is safe to conclude that the new-towns approach, at least by itself, will not bring about a flow of traffic that is optimum from the point of economic efficiency. In fact, some of the new towns probably have contributed to congestion on certain routes. On the other hand, new towns patterned after the Don Mills Communities should reduce travel costs and contribute to a more efficient use of resources.

Administrative feasibility poses no problem, and the new town idea appears to be increasing in popularity. If new towns had their own employment base, they could sharply reduce commuting costs and combine the economic advantages of agglomeration with the amenities of suburban living. Even though new towns have not reduced congestion, and perhaps not even its rate of growth, this alternative and the broader subject of transportation planning relative to land uses deserves a great deal more attention. [For a recent survey of a number of transportation-land use alternatives, see Richards (76).]

Miscellaneous—

18. Provide Modern Rapid Transit—The study prepared for the U. S. Department of Housing and Urban Development (69) suggests that there are two approaches to providing modern urban rapid transit: gradualism and new technology.

Gradualism emphasizes "...changes in and additions to existing transportation, in a manner that forces no wholesale replacement or abandonment of existing vehicles and facilities" (69, p. 22). Alternatives considered within this category are (a) safer, lower-pollution, conventional automobiles, (b) up-to-date rail rapid transit and buses, and (c) novel suburban collection and central distribution systems for transit passengers. A particularly interesting facet of (c) is the proposed dial-a-bus system, a hybrid between an ordinary bus and a taxi, that would pick up passengers at their doors or at a nearby bus stop at a specified time within 10 min after a telephone call to a bus-dispatching center.

> At the one extreme it might offer unscheduled single passenger door-to-door service, like a taxi, or multi-passenger service, like a jitney. At the other extreme it might operate like a bus service, picking up passengers along specified routes which could include several home pick-ups. The system might also be programmed to rendezvous with an express or line-haul carrier, and in serving as either a collector or distributor, provide the opportunity to improve the complete transportation service (77, p. 59).

New technology implies "...innovations so substantial that they are no longer merely incremental changes in and additions to existing transportation. Ultimately, this new technology may be expected to render parts of the existing transportation system obsolete" (69, p. 49). Consequently, this alternative might be considered an institutional change. Included in this category are (a) personal transit, small personal vehicles traveling on high-speed automatic guideways; (b) dual-mode transit, automatic guideways accommodating both personal transit vehicles and private automobiles from the city streets; and (c) novel suburban collection and central circulation systems for transit passengers. Because (b) does not require separate overlapping route systems for public and private use, it is claimed that the cost per vehicle-mile would be equal to or lower than that for urban freeways, and average speed and capacity would surpass the best of urban freeways (69, p. 51).

Whether or not these optimistic claims are justified at the present time, the studies suggest that bold approaches are capable of making transit more competitive with the private automobile by offering commuters comfort, privacy, and fast portal-to-portal service. The new technology, in fact, might offer a commuter a choice of driving his own automobile to work, using publicly provided, personal rapid transit, or using some combination of these. Thus, the small, electric atuomobiles proposed in alternative 16 might be integrated into a rapid transit system.

It is difficult to evaluate alternatives beyond our range of experience. Many will consider these and other alternatives described in Tomorrow's Transportation (77) impractical. However, the horseless carriage may have been considered even more impractical by our great-grandfathers. Fortunately, it is not necessary for an urban area to commit itself to either gradualism or the new technology. Demonstration grants can finance experiments with new technologies while present service is improved by gradualism. Something approaching portal-to-portal service proved quite successful in a demonstration project in Peoria, Illinois, described in alternative 8.

Because there are so many uncertainties during the long-run, predictions about the relative efficiency of investment in one mode as opposed to another are highly speculative. To the extent that investment in public transit decreases the demand for automobile travel (or at least reduces the rate of growth in this demand), it reduces congestion (or the rate of growth in congestion) on urban networks. [It is generally agreed that in order for transit to be competitive with the private automobile, it must offer comparable service at comparable or lower prices. Given the trends in residential density, the greater dispersal of economic activity, the price structures of the two types of service, and the fact that the behavior of Homo sapiens is strongly conditioned by habit, it is becoming increasingly difficult for conventional transit systems to lure commuters out of their automobiles. For example, Meyer, Kain, and Wohl argue that time reductions in line-haul phases of transit trips may not be sufficient to overcome the disadvantages of conventional systems relative to the private automobile in the collection and distribution phases (78). Considerations of this nature have led to some of the less conventional proposals (77). However, recent studies by Beshers (79) and Leavens (80) challenge some of the assumptions and figures used by Meyer, Kain, and Wohl in their comparative cost and travel time calculations.] Whether or not the allocation of resources is improved depends upon the investment mix among the different types of services relative to costs and demand.

Many transit companies do not break even financially, particularly if long-run capital costs are counted. Approval of the BART system for the San Francisco bay area and the Metro system in Washington, D. C., indicates that rail rapid transit is still politically feasible in certain areas. The Peoria subscription demonstration project indicates that certain incremental improvements are financially, administratively, and politically feasible (56). More imaginative alternatives such as dial-a-bus and dual-mode systems have yet to be tested, but research suggests they are administratively feasible (77).

19. Build Additional Freeways—For the past three to four decades, and particularly since the Interstate Highway Act of 1956, the greatest proportion of public investment in urban transportation has been in additional highway capacity. Although average speeds on urban freeways during peak hours usually are considerably below the 45 to 50 mph corresponding to the high levels of service highway planners have aimed for, there has been an increase in average automobile speeds in many cities that have had major freeway programs (81). New York City may be an exception, because frequently it is claimed that surface travel requires more time today, particularly in lower Manhattan, than at the turn of the century. Urban freeway programs have been the subject of considerable controversy and the object of a great deal of local opposition, yet they have been successful in facilitating the movement of more people by private automobile.

Judged by how scarce resources are allocated, however, the prices paid by the peak-hour users on the urban freeways built to serve them are considerably below the long-run as well as the short-run marginal costs. If the right-of-way, construction, and other costs incurred to provide the service are allocated to the commuter (and most transportation planners and highway engineers with whom the author has talked agree that the urban freeways under construction or being planned are primarily intended to serve the commuter), then commuters using many of these facilities are heavily subsidized. This is of particular importance in evaluating freeways, because user charges on nontoll facilities range approximately from 0.8 cents to 1.4 cents per vehicle-mile. On the basis of these figures Fitch and Associates suggest that user charges may range from 4 cents to 10.6 cents per vehicle-mile below the peak capital costs for urban freeways where the costs per lane-mile range from $250,000 to $4 million. If the differential between user charges and costs is 5 cents per vehicle-mile (corresponding to a lane-mile cost of $2 million), this comes to $1.00 for a 20-mile round trip. The lane-mile costs for the highways proposed in the 1959 transportation plan for Washington, D. C., were estimated to average $2.35 million (2, pp. 130, 265). This is significant in view of the estimate by Moses and Williamson that a round-trip automobile toll of $1 would divert 38 percent of the Cook County (Chicago) automobile commuters to public transportation (82). The author has made no attempt to calculate the average lane-mile cost of the most recent highway plan for Washington, D. C., but he has made some simple calculations based on the average cost per lane-mile of the urban portion of the Interstate System. Right-of-way, engineering, and construction costs for four-lane freeways averaged a little over $500,000 per lane-mile during 1965-66 (83, p. 242). For costs of $500,000 per lane-mile, peak-hour volumes of 2,000 vehicles per hour for two hours per day, 250 days per year, nonreversible lanes, an expected economic life of 30 years, the 10 percent discount rate (or capital recovery factor of 0.1061) presently recommended by the U. S. Bureau of the Budget, and average user charges of 1.4 cents per vehicle-mile, the vehicle-mile difference between cost and user charges is 3.9 cents. Increasing the number of days to 300 lowers the discrepancy to 3 cents. For lane-mile costs of $12 million (slightly less than those of the Center Leg and the South Leg of the most recent freeway plan for Washington, D. C.), the discrepancy per vehicle-mile becomes $1.26 on the basis of 250 days, and $1.05 for 300 days.

Given the present pricing, or better, nonpricing, basis for planning additional investment in urban freeways, this alternative holds no promise of producing optimum traffic flows. In fact economic efficiency may even be impaired in some instances. However, because of the pressures exerted by various vested interests as well as certain institutional rigidities, it is likely that the preponderance of public investment in urban transportation will be in urban freeways in the foreseeable future. One of these rigidities is the transportation planning process itself. For a description of this process, see Urban Mass Transit Planning (84). For critical evaluations, see the recent contributions by Morehouse (85), and by Kain (36).

If transportation planners can break out of what Kain terms the "preference for pure technologies," wherein transportation planning is posed as "...a choice between investment in roads for private automobile use or a rail rapid transit system ..." (36, p. 19), much more efficient freeways might be constructed to provide high levels of bus transit service during peak hours, and high levels of automobile service during off-peak hours. This suggestion is particularly significant inasmuch as 68 percent of all journeys to work by public transit in 1960 were by highway-based vehicles (36). Bus transit has impressive advantages over the private automobile in terms of passenger capacity per lane (81). Structuring freeways so that bus riders could count on high-speed service, perhaps better than they could get from their automobiles, could change the relative demand for the two modes significantly. However, after freeways designed exclusively for automobiles and trucks have been completed, it is difficult and costly to modify them. And as Kain argues, "...their potential [for bus rapid transit] is less than if they had been initially conceived, planned, and designed in these terms" (36, p. 21).

The question of whether urban freeways presently break even in a financial sense is still a question of some dispute (34). Undoubtedly some do and some do not. Experience has shown this alternative to be administratively feasible. However, its indefinite political feasibility appears in doubt. [For example, see The Freeway Revolt (88).]

SUMMARY

The results of the evaluation of the alternatives are shown in Table 2. In descending order of their approximate efficiency ratings, they may be summarized as follows:

1. No alternative satisfies all of the criteria.
2. No alternative satisfies the efficiency and the feasibility criteria.
3. Alternatives 2, 15, and 1 satisfy the efficiency criterion, but 2, use marginal-cost pricing and 15, allow congestion, presently do not satisy the political feasibility criterion, and 1, make compensating payments, does not satisfy the administrative feasibility criterion.

4. Alternatives 8, 12, 4, 3, 9, 10, 11, and 16 would improve economic efficiency primarily by affecting the flow of traffic (and possibly even yield a second best solution). The second best solution refers to a situation where the allocation of resources and hence the level of satisfaction or net benefits is suboptimal but is the best that can be achieved in the face of existing constraints. Many economists believe that marginal-cost pricing is also the appropriate policy to achieve the second best, St. Clair (34) and Wohl (35), notwithstanding. Alternative 8, improve transit service, and alternative 12, apply traffic engineering techniques, probably would satisfy both feasibility criteria. Alternative 4, apply zone pricing, probably would satisfy the administrative but not the political feasibility criterion. Alternatives 3, increase parking rates, 9, shift travel to off-peak hours, 10, stagger work hours, 11, encourage car pooling, and 16, reduce automobile size, apparently would satisfy the administrative feasibility and might satisfy the political feasibility criterion.

5. Alternatives 7, reduce transit fares, 8, improve transit service, 11, encourage car pooling, 16, reduce automobile size, 18, provide modern rapid transit, and 17, build new towns, if pursued vigorously, might improve economic efficiency by significantly reducing air pollution and noise costs as well as by affecting traffic flows.

6. Alternatives 5, increase fuel taxes, 6, increase automobile excise taxes, and 4, apply zone pricing, might improve economic efficiency and pass the administrative feasibility test but would fail the political feasibility test.

7. Alternative 17, build new towns, passes both the feasibility tests but its ability to improve economic efficiency appears uncertain.

TABLE 2

EVALUATION OF COMMUTER TRANSPORTATION ALTERNATIVES

Alternatives	Criteria[a]					
	Economic Efficiency (optimum traffic flows)	Institutional Constraints				
		Break Even	Administrative Feasibility	Political Feasibility	Equity	Community Goals
Short-Run						
Price Changes:						
1. Make Compensating Payments	I or II	—	No	Yes		
2. Use Marginal-Cost Pricing	I	Yes (surplus)	Yes	No		
3. Increase Parking Rates	II	Yes (surplus)	Yes	?		
4. Apply Zone Pricing	II	Yes (surplus)	Yes	No		
5. Increase Fuel Taxes	?	Yes (surplus)	Yes	No		
6. Increase Automobile Excise Taxes	?	Yes	Yes	No		
7. Reduce Transit Fares	?	No	Yes	?		
8. Improve Transit Service	II	?	Yes	Yes		
Institutional Changes:						
9. Shift Travel to Off-Peak Hours	II	—	Yes	?		
Miscellaneous:						
10. Stagger Work Hours	II	—	Yes	?		
11. Encourage Car Pooling	II	—	Yes	?		
12. Apply Traffic Engineering Techniques	II	?	Yes	Yes		
13. Restrict Vehicles	?	—	Yes	No		
14. Allow Congestion	O	—	Yes	Yes		
Long-Run						
Price Changes:						
15. Use Marginal-Cost Pricing	I	?	Yes	No		
Institutional Changes:						
16. Reduce Automobile Size	II	—	Yes	?		
17. Build New Towns	?	—	Yes	Yes		
Miscellaneous:						
18. Provide Modern Rapid Transit	?	?	Yes	Yes		
19. Build Additional Freeways	?	?	Yes	?		

[a] I, would produce an optimum flow of traffic; II, would not produce an optimum flow of traffic but would lead to a more efficient solution; O, would not produce an optimum flow of traffic and would not lead to a more efficient solution; ?, uncertain; and —, not applicable.

8. Alternative 13, allow congestion, passes the feasibility test but apparently would not improve economic efficiency.

9. Alternative 19, build additional freeways, is uncertain with respect to political feasibility and improvements in economic efficiency.

Some of the author's conclusions may be questioned. Because urban areas differ in such important trip-making determinants as economic base, per capita income, topography, and transportation alternatives, generalizations are difficult. Some of the alternatives cover a wide range of possibilities, especially improve transit service (8), build new towns (17), provide modern rapid transit (18), and, perhaps, build additional freeways (19). Depending on the assumptions, strong arguments could be made for or against these alternatives on the grounds of economic efficiency.

Not all of the variables and the interactions—the systems effects—can be treated. Because some of the alternatives are untried, one is forced to speculate. The costs of implementing road pricing, particularly by electronic or optical scanning, might prove so costly as to render marginal-cost pricing, alternatives 2 and 15, a second best rather than an optimum alternative. However, dynamic forces should not be overlooked. The political as well as the administrative feasibility of road pricing might change significantly within a decade.

Finally, the author's own values affect his appraisal. However, to the extent that the assumptions underlying the analyses of the alternatives portray technology, tastes, transportation alternatives, and other trip-making determinants in actual situations, the author believes that his conclusions merit consideration. Consequently, he has a greater degree of confidence in his evaluation of alternatives 1, make compensating payments, 2 and 15, use marginal cost-pricing 4, apply zone pricing, 5 and 6, increase fuel and automobile excise taxes, 8, improve transit service, 12, apply traffic engineering techniques, and 14, allow congestion.

CONCLUSIONS AND POLICY IMPLICATIONS

The emphasis in this paper has been on illustrating how economic analysis can assist in the administration and planning of urban transportation systems and on suggesting a framework for evaluating alternatives. As a result of the analysis, certain conclusions emerge that have important policy implications.

First, a great deal more attention should be devoted to basic economic concepts, and particularly to price. The allocating and rationing functions of price in a market economy are poorly understood, and its potentials for achieving social and economic objectives are grossly underestimated. For normative or prescriptive purposes, it can be employed to increase the level of satisfaction obtained from resources that are scarce. Even where there are formidable problems in pricing transportation services according to marginal social costs, the principle is quite important because it facilitates understanding the nature of an efficient solution and the problems of attaining this goal. For example, it was suggested that some of the alternatives might be regarded as substitutes for a pricing solution, particularly if they were pursued simultaneously and vigorously. However, the failure of people to voluntarily stagger their hours of work within the peak, to shift their travel times to off-peak hours, to carpool, to switch to public transportation, or to live in new towns in significant numbers suggests an even more basic point: These alternatives would contribute more to economic efficiency if employed in conjunction with a pricing scheme rather than in place of one. Increasing the price of peak automobile travel would encourage commuters to carpool and to use public transportation. It is the absence of a market for motor vehicle travel that makes it difficult to implement nonmarket alternatives, and for them to achieve significant results.

If the primary goal is not economic efficiency, positive or descriptive economic analysis can assist in predicting the results of alternatives. It is significant that if the goal is to reduce congestion, especially during the peak hours, a pricing scheme probably would be the most effective measure. Conceivably, such an analysis might result in a recommendation to increase prices by amounts greater than necessary to achieve flows that would be optimum in the context of welfare economics.

Second, even though there is no market for automobile travel except on toll roads, the general question of efficiency in urban transportation can be approached from the point of view of eliminating market imperfections that prevent prices from performing their rationing and allocating roles properly. The market imperfections that work against economic efficiency in automobile travel, particularly for the journey to work, include the following: (a) price distortions as a result of external costs (especially congestion, noise, and air pollution), cross-subsidies among groups of automobile users (particularly where facilities are built primarily to serve commuters), disparities concerning the amounts and the terms of federal financial assistance to different modes, and differences in local property tax treatment of rights-of-way; (b) differences in the perception of prices as a consequence of differences in the means of collecting the user charges (i.e., excise taxes on automobiles and parts, license and registration fees, and fuel taxes vis-á-vis the transit fare box) and the tendency to overlook or minimize the fixed or capital costs of the automobile; (c) the absence of alternatives to the private automobile for many commuters; and (d) inadequate information on the part of planners and policy-makers concerning the range of possible alternatives and their respective costs and benefits. A variety of measures might be employed, but a pricing scheme would be a very potent means of reducing the magnitude of these imperfections, with the possible exception of (d), and of raising the level of economic performance or urban transportation systems.

Third, those involved in the administration and planning of urban transportation systems should ponder the conclusion that some of the alternatives that apparently would increase the net benefits of transportation are currently politically unacceptable. It is tempting to conclude that people rank other goals such as equity higher than economic efficiency. This may be the case, particularly if it appears that some groups will be greatly disadvantaged, yet it is also possible that people are not sufficiently informed about the available alternatives and their costs and benefits. Moreover, some of the alternatives will improve the welfare of individuals only if there is some collective mechanism to permit their accomplishment. Decisions on the part of a few individuals to change their mode of travel or to carry more passengers in their cars will not decrease their travel times, or those of the rest of the commuters.

Also, care should be taken to avoid what Kain calls the "premature imposition of constraints"

> ...when administrators, engineers, planners, and other technicians decide that a particular alternative would be unacceptable for political reasons or to the public. Judgments of this kind suffer from several shortcomings. First, they imply that there are certain absolutes. Yet my experience with democratic societies suggests that the community can be educated and public opinion can be changed and whether something is worth doing in the political arena depends on its costs and benefits. Second, they imply that technicians are more capable of determining political feasibility or public acceptability than policy makers or responsible ministers. This I regard as both improbable and illegal and inappropriate siezure of power by technicians that is inimical to the principles of our democratic societies (36, p. 10).

Kain goes on to warn that the "worst aspect of 'premature imposition of constraints' is that such action frequently leads to a situation where certain alternatives are no longer considered at all" (36, p. 10).

Again, road pricing is a case in point. People are accustomed to paying higher rates for parking and for long-distance telephone calls during working hours, and for air travel and for food and lodging at resorts during holidays and summer months. Can administrators, engineers, planners, and other technicians predict with confidence that the public would overwhelmingly reject the idea of pricing intraurban travel according to marginal social cost if (a) the logic of the proposal were clearly presented; (b) the benefits were explained (e.g., faster travel time during peak hours, lower levels of air pollution, a source of revenue, reduced needs or requirements for additional freeway capacity, but better information for planners concerning the demand for travel on all modes); (c) transit alternatives were increased to permit people a wider range of choice, particularly to avoid severely penalizing those who were "tolled off"; and (d) the scheme were accompanied by the reduction, or complete elimination or refunding, of all other user charges? This alternative, or higher parking charges, would be an excellent candidate for a demonstration project.

Fourth, more effort should be devoted to making the most efficient uses of previous transport investments, particularly before large-scale investments in new capacity are undertaken. Again, Kain puts it well when he claims that we are obsessed with a "long-range planning syndrome," or "...the tendency of most current metropolitan transport planning ...to deal with conditions and problems 20 or 30 years in the future .... It is primarily present or near-term conditions that determine choices in the near future" (36, p. 13). He criticizes this orientation on the grounds that it builds a pronounced construction bias into the studies, and that it implies that existing facilities are being used most efficiently. It also raises a more basic question: If current facilities are used inefficiently, how can one expect future facilities to be efficiently used?

A number of short-run alternatives were evaluated, and some were suggested to be logical candidates to increase net benefits in the short-run. However, it was pointed out earlier that such obvious expedients as staggering work hours and car pooling need the goad of price to be most effective. Greater efforts should be exerted to discover other ways to make better use of the existing transportation system. One possibility, which has received comparatively little attention to date, is to discover means to make greater use of taxicabs for the journey to work.

Finally, it should be pointed out that the alternative that probably would be suggested by most economists—to synthesize a market and, insofar as possible, to charge prices equal to marginal social costs—is not without its detractors (16, 34, 37). [It is not possible within the confines of this paper to develop and respond to all of the objections to road pricing. At least two studies already have evaluated the major objections (20, 38). Some of the objections are valid; however, the critics have all but ignored three important facets of pricing and economic efficiency in the context of the urban economy as a whole. First, they have concentrated on the rationing role of price almost to the complete exclusion of its allocating role. As well as limiting demand, prices direct individuals to substitute services. Short-run substitutes include different routes, different times of travel, different modes of travel, and car pools in lieu of the single-occupant vehicle. In the long run, the range of choices also would include changes in residential (or work) locations. Second, the critics have focused on only one of the external costs of motor vehicle travel, congestion, and have largely ignored other externalities such as air pollution, noise, loss of aesthetics, and disruption of neighborhoods that frequently result from the construction of urban freeways. Third, they have disregarded the wider effects on the urban economy of serious distortions in the price of a fundamental service. Although the results of such a price distortion on resource allocation and the prices paid by consumers for final products are quite difficult to quantify, such distortions have important implications concerning the length and the number of trips by different modes, the amount of investment in additional capacity among the different modes, the location of economic activity, and urban ecology.]

Even Vickrey, the leading advocate, warns that economic efficiency is not the only desirable social goal, and cautions against blind obedience to the marginal-cost principle (39). However, he emphasizes that some of the objections to marginal-cost pricing also apply to other pricing formulas, and that public enterprises cannot ignore marginal-cost considerations in their price and investment decisions (40). Before the implementation of any pricing scheme, even on an experimental basis, careful attention should be given to considerations such as the possibility of undesirable impacts, however determined, on certain groups.

For those inclined to dismiss lightly the idea of creating a market for motor vehicle travel or otherwise raising the price of motor vehicle trips (e.g., by increasing parking rates), the author has a parting thought. During the depression of the 1930's, Keynes urged central governments to use the monetary and fiscal tools at their disposal to raise levels of employment and income. At the time, his recommendations were not consistent with traditional economic doctrine and conventional political philosophy. However, except for a few holdouts, changes in Federal Reserve discount rates, changes in federal income and excise tax rates, and depreciation allowances are now considered orthodox practice—especially during periods of recession and inflation. In 1968, landing fees for small planes were increased in the New York, Boston, and Washington, D. C., metropolitan areas following a period of unusually long delays for aircraft using the major airports in these areas (41). Prior to these increases, both the Assistant Secretary and the Deputy Assistant Secretary for Policy Development of the U. S. Department of Transportation suggested higher landing fees as a means of improving economic efficiency at congested airports (42). More recently, both the Transportation Department Secretary and the Assistant Secretary for Policy and International Affairs in the Republican Administration have raised the possibility of road pricing (43, 44). These developments probably would not have surprised Keynes, who in the last pages of his General Theory of Employment, Interest and Money wrote: "...the ideas of economists and political philosophers, both when they are right and when they are wrong, are more powerful than is commonly understood. Indeed, the world is ruled by little else" (45, p. 383).

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Appendix

SUMMARY OF THE ROAD-PRICING ARGUMENT

A hypothetical urban freeway will be examined, and, in order to concentrate on external costs, it will be assumed that maintenance and traffic control costs are so small that they may be ignored.

The Short-Run

The normative problem in the short-run may be regarded as how to make the most efficient use of certain resources in fixed supply, given the total amount of resources, tastes, institutions, and technology. The focus will be on fixed highway capacity, and substitute and complementary relationships of automobile travel vis-á-vis other goods and services will be ignored. The hypothetical freeway will be treated as a public enterprise, and it will be assumed that the crucial decisions are concerned with price (particularly tolls) and output (traffic volume).

As explained earlier, vehicle operating, travel time, and risk costs are largely internal to road users as a group. However, to the degree they result from delays and congestion, they are external to individual road users. The air pollution and noise costs are largely external to road users at all volumes of traffic. For simplification, the congestion costs that are external to the individual user but internal to road users as a class will be referred to as the Type I costs, and that portion of the air pollution and noise costs that are external to road users will be referred to as the Type II costs. The road users' internal and external costs combined constitute the total social costs of motor vehicle travel in the short-run.

In Figure 1 (which is not necessarily drawn to scale), the abscissa represents traffic volume in vehicles per hour (vph), and the ordinate represents costs in cents per vehicle-mile. If the Type II costs are ignored, then for the hypothetical freeway, the functions representing the short-run average and marginal social costs per vehicle-mile may be illustrated by SRAC and SRMC respectively. Because, by definition, the function SRAC excludes any costs that are external to road users, it is also the average private cost function. And because it shows the personal marginal costs per vehicle-mile that additional drivers will experience, it is also the marginal private cost curve.

At low traffic volumes, vehicles will not interfere with each other appreciably, and there will be no external or spillover costs as additional vehicles enter the facility. Consequently, average and marginal social costs may be assumed to be very nearly equal and constant. However, as traffic volumes rise above the level OX_0 vph, traffic density will reach the level where additional vehicles will significantly impede the flow of traffic, and the contribution to total travel costs of additional drivers (represented by the SRMC curve) will exceed their own personal costs (represented by the SRAC curve). Normally, the SRAC curve is the volume-price curve as seen by the driver, and the equilibrium volume of traffic will be determined by the intersection of this function with the demand function DD' (which may also be interpreted as the marginal social benefit curve). (For simplification, it will be assumed that there are no fuel taxes. The inclusion of fuel taxes would not change the shape or the position of the social cost functions, because taxes are transfer payments and not opportunity costs. If fuel taxes are included, however, then the SRAC function no longer describes the volume-price relationship as perceived by the road users). This volume, OX_1 vph, results in net benefits equal to LDG, i.e., total benefits $ODGX_1$ minus total costs $OLGX_1$. This is not the largest amount of net benefits that might be realized. The largest sum, BDEF or total benefits $ODEX_2$ minus total costs $OBFX_2$, is found at the intersection of the demand function DD' with the marginal cost function SRMC, corresponding to a volume of OX_2 vph.

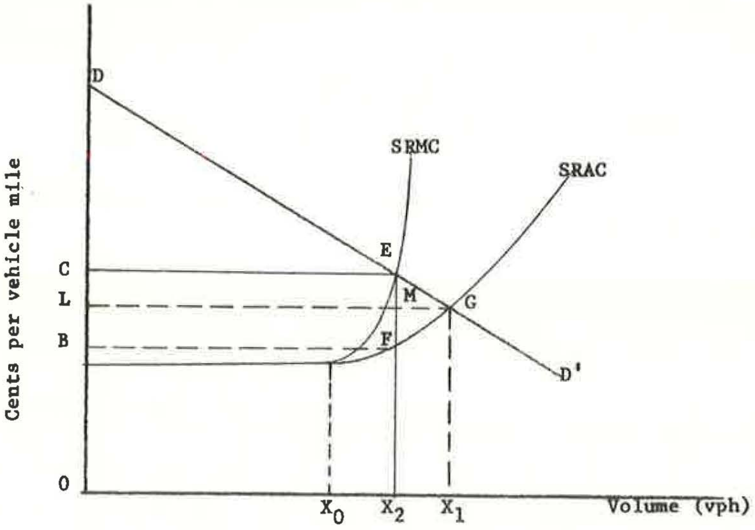

Figure 1. Short-run cost, demand, and pricing relationships.

The failure to achieve an equilibrium with higher net benefits is no fault of the road users, for they are acting rationally, given the prices and costs confronting them. Consequently, what is needed is a method to capture all of the additional social costs created by the additional driver so that he will include them in his decision-making. A toll equal to the difference between the SRAC and SRMC functions will accomplish this. With such a toll, the SRMC function becomes the drivers' cost and price-volume curve. If all drivers pay a toll equal to EF, then equilibrium will result at OX_2 vph, or at the volume that yields the largest net benefits. [For a more detailed analysis and a mathematical proof that the optimum congestion toll would exactly cover the capital costs of a highway of optimum capacity (i.e., that the efficient long-run solution is also the efficient short-run solution), given the assumptions stated earlier, see the contributions by Mohring (21, 66).]

Diagramatically, the reduction in total benefits, X_2EGX_1, is smaller than the reduction in total costs (the difference between the rectangles $OLGX_1$ and $OBFX_2$). Because the remaining drivers must pay a higher price, X_2E as compared to X_1G, and because a toll revenue is included in the net benefits, it may be difficult to understand why economists claim the volume OX_2vph is the most efficient. In addition to being the volume that yields the greatest net benefits in the sense developed in this paper, it can also be said that, at the price X_2E corresponding to that volume, only those who value that particular service (i.e., the route, direction, mode, occupancy ratio, and time of travel) by an amount equal to or greater than the additional costs to society of providing the service will consume it. Those who value the particular service less than its marginal social costs will choose other alternatives. To argue that the efficient solution improves the welfare of society as a whole requires further assumptions and value judgments, the most important of which are (a) that benefits as revealed by willingness to pay are an adequate representation of individual utilities and (b) that society is better off following a change in resource allocation if the increases in net benefits to some exceed the decreases in net benefits to others. Value judgments of this type cannot be avoided when making decisions about public projects, whether the decisions are made on the basis of an economic analysis or as part of the conventional urban transportation planning process. What is important is that the ethical and value considerations be recognized and explicitly stated. Earlier sections have additional comments on this general problem.

But to conclude that the volume OX_2 vph is optimal is to ignore the Type II externalities, the air pollution and noise costs of motor vehicle travel. Much less is known about these costs than about the Type I costs (particularly the operating costs), but it is known that the amounts of air pollution and noise that a motor vehicle produces increase as the vehicle accelerates and decelerates in response to the higher densities associated with higher traffic volumes (87). Consequently, it is safe to assume that at some point the average and marginal cost functions of air pollution and noise begin to rise as traffic volumes increase. For simplification, it will be assumed that the functions describing the Type II costs have the same general character as the functions describing the Type I costs.

In order to arrive at an aggregate marginal social cost function, it would be necessary to add the Type II to the Type I costs in Figure 1. This would shift the SRAC-SRMC functions upward and would result in a higher price and a lower volume at the new equilibrium.

However, the presence of the Type II costs has another important implication: To the extent that there are external costs at all volumes of traffic, efficiency tolls would be in order, even in the absence of congestion! It would be erroneous to conclude, however, that air pollution and noise inevitably result in external costs. Under favorable wind and temperature conditions, the air pollution costs might be negligible or even zero, at least in the short-run. Similarly, motor vehicle noise might be completely masked by a thunderstorm. It is difficult to imagine instances, however, in which motor vehicle noise and air pollution would produce external benefits.

The Long-Run

In the long-run, the normative question is how to obtain the maximum net benefits from resources when plant scales (including the capacities of highways) can be changed. Although technology, tastes, and institutions also can change over time periods involving several years, it must be assumed that during the period in question these influences are relatively constant, or that they change in predictable ways. In the context of a public enterprise, the crucial questions of optimum price and output over the long-run involve estimates of optimum plant scale, given anticipated demand and costs.

The long-run costs are summarized in Table 1, and the long-run demand for travel in the discussion of alternative 15. The normative guide for the short-run applies with equal force to the long-run: at any point in time, the volume should be such that P = SRMC. If simultaneously P = SRMC = LRMC, capacity is optimal, and the public enterprise (i.e., the highway) is in long-run equilibrium. If P = SRMC > LRMC, capacity should be expanded to the point that P = SRMC = LRMC and, conversely, if P = SRMC < LRMC.

These price, output, and capacity relationships are illustrated in Figures 2 and 3. To simplify the explanation, it will be assumed that there are constant returns to scale, and that the factors of production are perfectly divisible (i.e., there are no discontinuities in the cost functions). To be consistent with Table 1, A will denote all costs associated with the construction and the existence of roads, and B will denote all costs resulting from traveling on roads. For the time period in question, B represents SRMC, B + A represents LRMC, and the difference between the two is the long-run capacity costs, with all costs expressed in cents per vehicle-mile. It will also be convenient to assume that the SRMC function has the same characteristics as its counterpart for fuel or running costs in thermal-electric plants, i.e., practically constant up to the rigid capacity limit, X_0, and almost infinite at that point. If air pollution and noise costs are disregarded, then B corresponds to the average private cost function as well as the SRMC function.

Suppose that the demand function in Figure 2 initially is D_4. If the price that the drivers perceive is OB, then the number of trips that they will want to take during the time period will be OX_1 vph. However, with a capacity of only OX_0 available, the de-

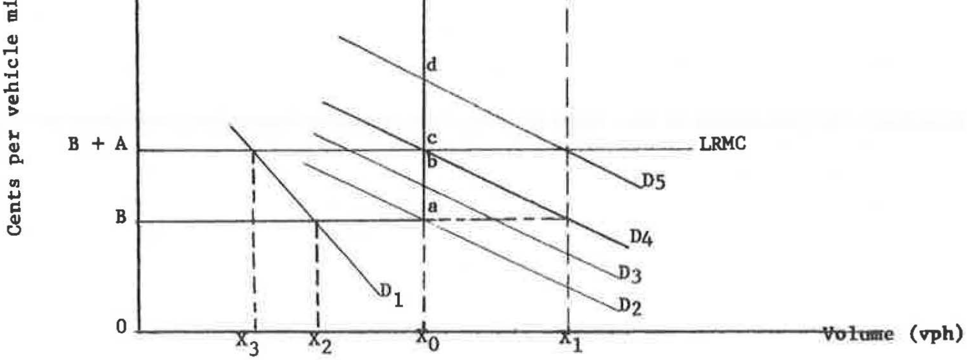

Figure 2. Long-run cost, demand, capacity, and pricing relationships for a single time period.

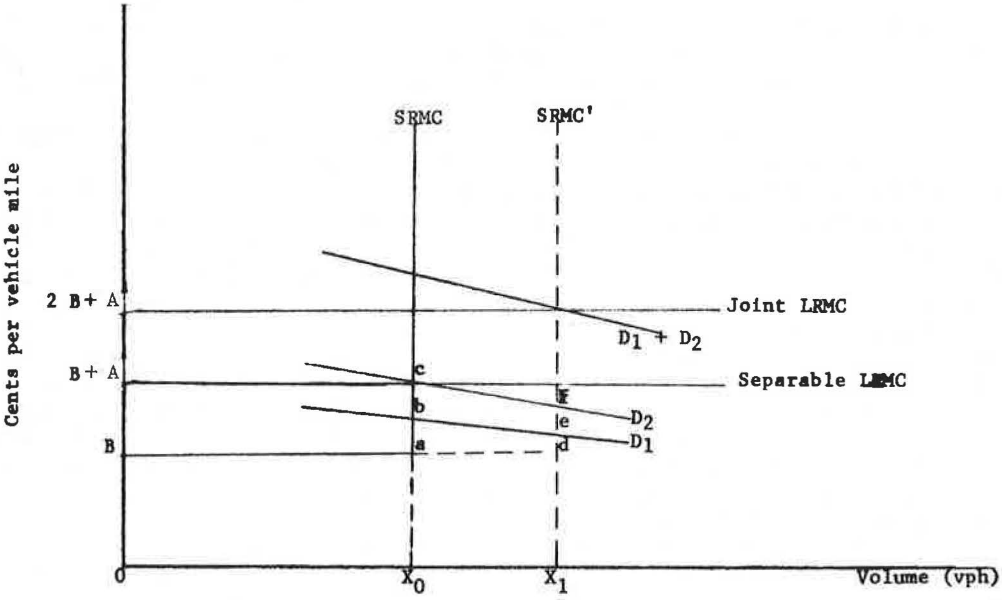

Figure 3. Long-run cost, demand, capacity, and pricing relationships for two time periods.

nand at the price OB will exceed the capacity of the facility by X_0X_1 vph. In order to ation the service so that those who value it most (as indicated by ability and willingness o pay) receive it, it is necessary to impose a congestion toll equal to ac cents per-ehicle-mile. A toll of this amount would result in an optimal utilization of capacity, .e., one that would maximize net benefits.

If the demand function shifted to D_5, the short-run volume would still be OX_0 vph, nd a toll equal to ad would be necessary to achieve an optimum utilization of capacity. Iowever, at a price equal to X_0d the SRMC would exceed the LRMC, and expansion to a cale of OX_1 vph so that P = SRMC = LRMC would be necessary to achieve long-run quilibrium. If the demand function shifted to D_3 a toll equal to ab would be necessary o achieve the most efficient utilization of capacity.

If the demand function shifted to D_1, there would be excess capacity of X_2X_0 in the hort-run at volume OX_2 vph corresponding to P = SRMC. For the functions D_1, D_2, and $)_3$, there is excess capacity over the long-run. Thus for D_1, the optimum scale would orrespond to OX_3 vph. Consequently, as the capacity represented by X_3X_0 wore out, t would not be replaced, because the information provided by the demand function indicates that the road users do not value the service provided by the capacity X_3X_0 enough o warrant the marginal social costs required to maintain it over the long-run.

From what has been said, it might be concluded that additional capacity is justified nly if the peak demand exceeds the LRMC in short-run equilibrium. While such a elationship is a sufficient condition, it is not a necessary condition. Assume that D_1 nd D_2 in Figure 3 represent demand functions for independent, nonoverlapping time eriods of equal duration, and that D_2 represents the peak demand. The optimum short-un solution calls for full utilization of capacity and, hence, equal volumes in both pe-iods, although the toll for D_2 (ac) would be higher than that for D_1 (ab). Neither demand unction by itself justifies expansion of capacity. However, because the periods do not verlap, they both can use the same capacity. By adding the two SRMC functions to the ong-run capacity cost function, a joint LRMC function, 2B + A, is obtained. If D_1 and $_2$ are also added vertically, then a joint demand curve for capacity, $D_1 + D_2$, is the esult.

If the joint demand for capacity equals the joint LRMC at the existing capacity level, e., if $D_1 + D_2 = 2B + A$ at OX_0 vph, then that capacity level is optimal. However, in

Figure 3, $D_1 + D_2 > 2B + A$ at capacity OX_0, and capacity should be expanded until long-run demand and marginal cost are equal, i.e., to the level OX_1. At the new equilibrium, OX_1, traffic volumes during both time periods would be at full capacity, and road users would still pay tolls (although the tolls—dt and de for D_2 and D_1 respectively—would be lower than at the smaller capacity). If $D_1 + D_2 < 2B + A$, capacity should be reduced.

To recapitulate: As in the single time-period analysis, optimum capacity is determined by the intersection of the joint demand and LRMC functions, and optimum prices and volumes are determined by the intersection of reparable demand and SRMC functions.

Relaxing the assumptions so that the examples approximate more closely actual situations complicates the analysis but does not change the normative rules. The fact that roads come in discrete sizes with lanes approximately 12 ft wide may render more difficult the decision of whether (and how much) to expand capacity. If the analyst is left straddling a fence because the optimum capacity appears to be 2.5 lanes in each direction, he should consider the possibility of constructing fewer lanes, and making one or more reversible during peak hours. Because of this "lumpiness" of investment and other influences resulting in deviations from optimum capacity (e.g., growth in traffic, errors in forecasting, and administrative failures), tolls must be flexible in order to bring traffic flows as close as possible to the optimum levels. Similarly, the assumptions of linear cost functions and of only two nonoverlapping time periods of equal duration merely facilitate graphic explanation.

In practice, long-run costs tend to fall in rural areas and to rise in urban areas, particularly those that are congested. Unfortunately, not a great deal is known about the interrelationships of the demand for travel, particularly noncommuter travel, during different hours of the day. Greater efforts should be made to build structural models to relate (a) the number of passenger trips stratified according to purpose, mode, time of travel, origin and destination, and route to (b) such trip determinants as monetary outlays, travel time, modal service characteristics, socioeconomic characteristics, and land uses.

A Statistical Sketch of Intercity Freight Demand

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•SUCCESSFUL STUDIES of the demand in other transport markets have been made, but no satisfactory efforts to model the demand for intercity freight traffic are known to the author. The recent effort by Sloss is noted (1), but difficulties, thought to be present in his techniques, may vitiate the results. This paper tries to fill this obvious gap. The estimates of the parameters of the rail and truck demand functions produced here do more, though, than fill a gap. They point to a number of interesting facts about intercity freight demand—facts not easily anticipated. It will be possible to make statements about the logic of the rate policies pursued by the two dominant freight modes during the postwar period and extrapolate these facts into tentative recommendations for future policies for both the carriers and the Interstate Commerce Commission (ICC).

The technique used in the present effort is regression analysis on time series for the period 1947 through 1966. Regression analysis is applied to obtain estimates of the income elasticity of demand, the price elasticity of demand, and the cross-price elasticity of demand for each of the two modes. Before the estimates and their significance are reported, there are a variety of issues to be considered concerning the sources for the data and potential problems common to the statistical techniques used.

Considerable care is taken in the selection of the data to be used. It is desired to employ absolutely the best data available so that the resulting estimates are in some sense definitive and as accurate as the historical record permits. The first decision is whether the analysis should be performed on a time series or on a cross section. The available data offer no choice. To obtain sufficient observations in cross section would require the use of the individual companies as the units of observation. This is not feasible. There are no statistics on the level of rates charged by individual carriers; further, if such information were available, it would reveal no (or little) internal variation, because in both the railroad and trucking industries the rates are set by regional rate bureaus so that interfirm variation does not exist. For the most successful effort to obtain cross-section estimates of the parameters of rail demand, see Roberts (2). The choice of time-series analysis is dictated.

The structure of the transport market is continually evolving, so that an ambiguity of using time-series data in the analysis is the applicability of parameters derived from the 20-year past to the short-run rate questions of the moment. Other considerations involved in the statistical techniques employed are postponed until the data series have been described.

THE DATA

The dependent variable in all our equations is the volume of freight offered for carriage by some sector of the economy to either of the two modes, rail or truck. Each year since 1923, the ICC has published Freight Commodity Statistics of Class I Railroads in the United States in which is reported the number of tons originated for each of 242 commodities that the railroads have hauled. These 242 commodities are aggregated into five commodity groups, on each of which the analysis has been performed. The groups are Products of Agriculture (hereafter cited as Agriculture), Animals and Products (Animals), Products of Forests (Forests), Products of Mines (Mines), and Manufactures and Miscellaneous (Manufactures). The ICC reports the freight volumes

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in tons only and takes no account of the distance the traffic has moved. For all 242 commodities taken together (hereafter cited as All Traffic), the ICC reports both tons and ton-miles of traffic moved. Where this information is available we estimate all equations twice, using both tons and ton-miles as the dependent variable. In fact, the choice of variable makes little difference in the results.

In 1965 the ICC discontinued the 242-commodity classification and the five commodity groups and instituted a new classification, the Standard Transportation Commodity Code (STCC). Using a splice of the old code and the STCC prepared by the Association of American Railroads, we reconstruct the 1965 and 1966 volumes of traffic for the commodities in each of the five commodity groups.

Data on truck freight volumes are far less complete. Trucking is dominated by private truckers who are under no obligation to report their activity to the ICC. The accepted estimates of truck volumes, including both regulated and unregulated carriage, are those published by the Transportation Association of America (TAA) in its annual pamphlet Transportation Facts and Trends. The TAA is a Washington lobby and research organization of the entire transportation industry so that there is no apparent incentive for it to slant its estimates. Accordingly, we use its estimates. The volumes are not disaggregated by commodity type, so that we cannot estimate equations for truck volumes corresponding to the rail equations by commodity group. Further, the TAA reports truck volumes in ton-miles only. However, to maintain full comparability between the truck and rail results as far as possible, we estimate the truck equations using both tons and ton-miles as the dependent variable. For this purpose, we obtain estimates of the truck volumes in tons by dividing the ton-mile figures reported by TAA by estimates of the average length of haul of truck freight for the corresponding years. The annual estimates of average length of truck haul are taken from a pamphlet, Motor Truck Facts, issued annually by the American Automobile Manufacturers Association.

There are as many considerations that complicate the choice of time series for the independent variables. To estimate price and cross-price elasticities requires rail and truck price indexes. In the selection of the rail price series we are presented with alternatives. On the one hand there is what we shall call the Ex Parte Price Index. Since World War II all general rate changes have been granted to the railroads by the ICC in ex parte proceedings. The ex parte changes have generally been allowed as percentage rate increases, uniform over a wide group of commodities. Since 1947 there have been 18 of these ex parte increases (all general rate changes have, in fact, been rate increases). If we begin by setting the 1947 rate at 100 percent and then compound this with the ex parte increases as they have taken effect over the years, we generate what we have called the Ex Parte Price Series.

Its usefulness as the price series for our final demand equations is marred by the fact that the railroads, in thousands of applications to the ICC, have put into force highly selective rate reductions (and some increases) that applied alone to very specific movements. Most of these selective rate changes have been made to improve the competitive posture of the railroads in specific situations; our ideal rail rate index should take these changes into account.

The ICC has in fact issued a little known rate index that does this job. The index, known as the RI-1 index, was issued for the years 1947 through 1966 as part of the Rail Waybill Study. The index was computed by taking the 1950 traffic movement shown by the 1950 Waybill Sample. This basic package of movements has then been revalued each year using the average revenues from corresponding movements for each year as the appropriate rates. The RI-1 index of rail rates on All Traffic was computed annually up through 1966. We require, in addition, price series for the five commodity groups and for the regions whose rail demand equations we are estimating. The RI-1 index was computed for each of these groups, but only up to 1961 for the commodity groups and to 1963 for the regions. We extrapolate these indexes for the years 1962 through 1966, constraining the estimates of each year to average out to the figure for the rate level on All Traffic in that year.

We require also a truck rate series. Again we have a choice from two possible series. One of these corresponds to the rail Ex Parte Rate Index described earlier.

It is a chronology of the across-the-board rate increases put into effect by the truck rate bureaus. Two such chronologies, for two different motor-carrier rate conferences, have been prepared by Josephine Olson for Del Steiner of Washington, D. C. They are nearly identical, suggesting that the different rate bureaus adhered to a common pattern of rate increases during the postwar period. This index of truck rates suffers from the same shortcoming as the Ex Parte Rate Index for railroads, namely, the failure to incorporate numerous specific rate reductions. Further, it takes no account of the imputed revenues of private and contract motor carriers.

There is, however, no analogue to the RI-1 rate index for the trucking industry, because the ICC has not made any waybill study of the trucking industry. The closest approximation to such an index that can be formed from the data available is the annual series of average revenue per ton-mile for truck freight. This is found by dividing the estimates of the total annual revenues of the trucking industry (including imputations for private trucking), as reported in the TAA's Transportation Facts and Trends, by the estimates of the number of ton-miles hauled by all trucks, as reported in the same source.

The shortcomings of this truck rate index relative to the RI-1 index of rail rates are twofold. First, it fails to maintain its weights constant from year to year, so that changes in the aggregate composition of truck traffic, as well as changes in the level of rates, are reflected in the year-to-year changes of average revenue per ton-mile. Second, we are without the data to specialize this index of truck rates by commodity groups as we have been able to do with the RI-1 index. For all its inadequacies, it is the best index available.

We need now only the time series that will permit estimates of income elasticities. For estimating the demand functions for All Traffic by rail and by truck we have selected gross national product (GNP) as our income series. GNP is entered in constant 1958 dollars, so that our regressions will be relating changes in traffic volumes to changes in the real income of the country. We deliberately do not adjust the GNP series in such a way as to make it an index of the production of physical, and hence transportable, output. Thus the substitution in the economy during the postwar years toward increasing the share of private and governmental services will be reflected in a lower income elasticity.

For estimating the regional income elasticities of rail freight demand we specialize GNP to represent gross regional products by multiplying the GNP series by the percentage of personal income accounted for by the states of each region for the respective year. The personal-income-by-state data have been taken from the U. S. Statistical Abstract. There is no better way to obtain gross regional products.

For estimating the demand equations for the five commodity groups, appropriate indexes of production have been entered in lieu of income series. Thus, for example, the volume of Products of Agriculture hauled by railroads is regressed on an Index of Crop Production compiled by the U. S. Bureau of the Census. The exact indexes of production, their sources, and the raw data series themselves are all given in the tables in Appendix A.[1] It is correctly observed that the substitution toward services and away from goods in the economy will not be reflected in the coefficients of these indexes of production; hence, these income elasticities will measure the performance of the railroads in increasing their traffic against the increase in output of physical goods potentially available to the railroads as traffic. To make a visual comparison of the trends of railroad rates and volumes during the postwar period easier, we have graphed a large number of these basic series. These graphs are shown in Appendix B.[1]

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[1] The original manuscript of this paper included Appendix A, tabulations of historical data, and Appendix B, graphs of historical data. The two Appendixes are available in Xerox form at cost of reproduction and handling from the Highway Research Board. When ordering, refer to XS-27, Highway Research Record 296.

STATISTICAL TECHNIQUE

We have committed ourselves to the use of regression analysis on time-series data. This method is frought with hazards that we would do well to examine.

We have specified the explanatory variables of our equations but have not specified the form in which they are to be entered. One obvious choice is between entering the data in natural form or in logarithmic form. The advantage of the latter is that the resulting coefficients are elasticities. Elasticities are desirable in that they are familiar as parameters of demand, and also in that they do not need dimensions (units of measurement). As desirable as the log form may be, that is not assurance that it is the better form to use, for we do not know that a straight line in log space fits the data as closely as a straight line in the space of natural numbers. This must be tested. Our choice between log and natural forms should be guided by our expectations as to the nature of the disturbance process. If the variance of the error terms were thought to be roughly constant over the interval of observations (in natural numbers), then regression using the natural numbers would preserve this homoscedasticity. If, on the other hand, the variance were thought to increase proportionally to the values of the arguments (i. e., constant coefficient of variation), then regression in log space would create homoscedasticity.

Because there is no a priori reason for suspecting one scheme of disturbances over the other, the best procedure is to test both models and choose the better after a comparison of the distribution of the residual terms. Three of the demand equations are estimated in both natural and logarithmic form. Examination of the residuals and coefficients of determination in each of the three cases yields the same conclusion: There is no marked tendency for either form to provide a better fit to the data. For reasons suggested then, the log form is chosen.

Examination of the residuals in this experiment provides still another important result: the absence of autocorrelation in the residuals. This obtains in all of the equations in which two or three arguments are used and in which reasonably high estimates of R^2 are obtained. The absence of autocorrelation has important implications. It suggests that we have escaped the "time-series problem"—the correlation of residuals resulting from the dependence of successive observations on each other. By taking observations on annual data, as opposed, say, to monthly data, we avoid the reduction in the effective degrees of freedom that such dependence implies. The absence of autocorrelation also suggests that no important explanatory variables are omitted from the explanatory set.

Another hazard attending the use of time-series data is the possibility of lagged adjustments, in this case, the possibility that traffic volumes of one year are determined by the prices of the prior year(s). The collinearity of prices and of lagged prices together with the shortness of the time series precludes testing for the appropriate lag structure. It is assumed that a year is sufficiently long and that volumes adjust to prices within the year.

The inclusion of the competitor's price level and an index of production in addition to own-price level in the explanatory set is sufficient to identify the relationship being estimated as a demand rather than a supply relationship. But it seems likely before the estimation is carried out that the price of so fully identifying the relationship will be excessive multicollinearity among the arguments. We are prepared to move in two directions to combat multicollinearity should it appear.

Of particular interest in this exercise is the effect of the competing mode's rate level on the volume of traffic hauled by the other mode, i. e., the cross-price elasticity. It would be disastrous therefore if the two price series proved collinear. One way to resolve this problem should it occur is to transform the two price series into two new orthogonal series in such a way that one of the new series highlights any divergences in the two original series. This was done by forming, from the original rail and truck rate series, an average rate series and a truck-to-rail rate ratio series. If the coefficient of the rate ratio term proves significantly different from zero, this is strong evidence that the cross-elasticity is significant. A second way to combat multicollinearity should it appear is to use more sophisticated regression techniques, such as constrained regression or Bayesian prior distributions, on the coefficients. Jumping ahead to our results momentarily, we find that excessive collinearity is not a problem, so that there is no need to use the Bayesian or the constrained regression techniques. Because of the importance of testing for cross-elasticity, however, we do perform the regressions with the transformed price series in addition to the regressions with the regular price series.

We discuss a final possible hazard in our regression procedures before proceeding to the results. It is quite probable that in our model causality flows in both directions, traffic volumes influencing price as well as price determining traffic volumes. If so, we may incur least-squares bias as a result of correlation between the independent variable and the error term. The correction for this is reformulation of our model into a system of simultaneous equations, the other equations modeling this reverse flow of causation. In what follows, we proceed with a single equation in the belief that this reverse flow of causation is not of the same order of magnitude as the one we are modeling. Short of building a complete model of the demand for intercity freight transportation, what follows is believed to be the most accurate estimation of the parameters of aggregate demand for rail and truck freight service that is possible with any existing statistics.

THE RESULTS

Altogether, a total of 12 markets are studied (Table 1). For each of the 14 dependent variables two sets of equations are estimated. The three explanatory variables of each of the two sets are:

Set A:	own rate	Set B:	average rate level
	competing mode's rate		truck-to-rail rate ratio
	index of production or GNP		index of production or GNP

The three explanatory variables of each set are entered in every possible combination—one at a time, two at a time, and all three at once. This means that 7 equations are estimated for each of the sets of explanatory variables. Thus, each of the 14 dependent variables is the dependent variable for two sets of 7, or 14, equations. All the equations so estimated are displayed in the tables in Appendix C. The dependent variable of each table is shown at the top of the page. Each line of the table shows the coefficient(s) (elasticities) of the explanatory variable(s) entered in one equation. The standard error of each estimate is placed beneath the coefficient. The columns on the right show the coefficient of determination, R^2, and the F-ratio for each equation. The equations with the B-set of explanatory variables are shown below those of the A-set. (The A-set for the Western District is missing because attempts failed to make the computer produce these estimates.)

Before making an inspection of those crucial estimates on which our interest centers, we make a general inquiry into our overall success in estimating the parameters of demand. For this purpose we have chosen a simple statistic: the percentage of coefficients that have the "correct" algebraic sign, correct in the

TABLE 1

TWELVE MARKETS AND ASSOCIATED FOURTEEN INDEPENDENT VARIABLES

Market	Commodity Group	Area	Measure
1. Railroads	All traffic	Entire U.S.	Tons
Railroads	All traffic	Entire U.S.	Ton-miles
2. Trucks	All traffic	Entire U.S.	Tons
Trucks	All traffic	Entire U.S.	Ton-miles
3. Railroads	All traffic	Eastern District	Tons
4. Railroads	All traffic	Pocahontas Region	Tons
5. Railroads	All traffic	Southern Region	Tons
6. Railroads	All traffic	Western District	Tons
7. Railroads	Agriculture	Entire U.S.	Tons
8. Railroads	Animals	Entire U.S.	Tons
9. Railroads	Mines	Entire U.S.	Tons
10. Railroads	Coal	Entire U.S.	Tons
11. Railroads	Forests	Entire U.S.	Tons
12. Railroads	Manufactures	Entire U.S.	Tons

sense that the estimated elasticity is of the same sign as conventional economic theory predicts, i.e., price elasticity, negative; cross-elasticity, positive; income elasticity, positive. A total of 324 coefficients is estimated. Of these, 236 or 73 percent have the correct algebraic sign. Details are given in Table 2.

Several points about the percentages in Table 2 deserve to be noted. Except for the Eastern District, Animals, and Mines, all categories have coefficients with the correct sign in more than two-thirds of the cases. There is no explanation for the failure of the Eastern District to do as well as the other districts, but the poor performance of Animals and Mines may be caused by the lack of competition between trucks and rails for the carriage of these goods, so that the inclusion of the truck rate reduces the overall performance of these equations. This, in fact, appears to be what happens. The cross-elasticity of rail volumes with truck rates is negative in every instance in Mines and Animals and is therefore "incorrect." We will have an explanation of these negative cross-elasticity terms later. They are not as incorrect as they may at first seem.

The equations with two and three arguments did substantially better than the equations with only a single argument, 75 percent correct vs 67 percent. Our best identified equations perform better than our more poorly identified equations. This is interesting; it appears that a complex of factors can explain the level of intercity freight traffic volumes to a degree that single factors cannot.

Another measure of the success of our equations is taken when truck volumes are substituted for rail volumes as the dependent variable. The explanatory-variable data are kept exactly the same. The a priori expectation is that the algebraic signs of the coefficients for truck rate and for rail rate (in the A-set) and for truck-rail rate ratio (in the B-set) should switch as the dependent variable is switched in order to keep own-price elasticity negative and cross-price elasticity positive. And this is precisely what happens! The coefficients change signs properly. This is powerful evidence that the estimating equations are accurately picking out the separate effects of the various explanatory variables.

TABLE 2

PERCENTAGES OF COEFFICIENTS OF VARIOUS GROUPS OF EQUATIONS HAVING THE CORRECT ALGEBRAIC SIGN

	Market	Commodity Group	Area	Measure	Percent
1.	Railroads	All freight traffic	Entire U.S.	Tons	71
	Railroads	All freight traffic	Entire U.S.	Ton-miles	83
2.	Trucks	All freight traffic	Entire U.S.	Tons	67
	Trucks	All freight traffic	Entire U.S.	Ton-miles	71
3.	Railroads	All freight traffic	Eastern District	Tons	50
4.	Railroads	All freight traffic	Pocahontas Region	Tons	92
5.	Railroads	All freight traffic	Southern Region	Tons	79
6.	Railroads	All freight traffic	Western District	Tons	83
7.	Railroads	Agriculture	Entire U.S.	Tons	88
8.	Railroads	Animals	Entire U.S.	Tons	38
9.	Railroads	Mines	Entire U.S.	Tons	58
10.	Railroads	Coal	Entire U.S.	Tons	67
11.	Railroads	Forests	Entire U.S.	Tons	92
12.	Railroads	Manufactures	Entire U.S.	Tons	88
	Explanatory Variables and Combinations				
13.	A set				71
14.	B set				74
15.	One argument in equation				67
16.	Two arguments in equation				76
17.	Three arguments in equation				73
18.	Overall average				73

Let us look now at the important parameters of demand that our efforts have been leading us to. In Table 3 we set out for ready reference that equation for each transport market that performs best. In general, this has been the equation with all three explanatory variables, except in those instances in which the truck rate is thought to be an irrelevant factor.

Inspection of these equations shows that in nearly all instances we obtain high R^2's, and, correspondingly, significant F-ratios. The standard errors tend to be small, making the estimates rather stable; the t-ratios of these coefficients, found by dividing the coefficients by the standard errors, show most of the estimates to be significantly different from zero.

TABLE 3

THE PRIME DEMAND EQUATIONS

Rail Demand—Aggregate				
RR Vol. =	-0.537 RR Rate	+0.628 GNP	-0.730 TK Rate	R^2 = 0.79
Ton-miles	(0.202)	(0.241)	(0.549)	F = 8.9
RR Vol. =	-0.696 RR Rate	+0.322 GNP		R^2 = 0.76
Ton-miles	(0.166)	(0.074)		F = 11.9
Rail Demand—Eastern District				
RR Vol. =	-0.317 RR Rate	+0.425 GRP	-1.786 TK Rate	R^2 = 0.88
Tons	(0.267)	(0.391)	(0.786)	F = 18.0
Rail Demand—Pocahontas Region				
RR Vol. =	-0.964 RR Rate	+0.925 GRP	-0.749 TK Rate	R^2 = 0.77
Tons	(0.368)	(0.374)	(0.829)	F = 7.9
Rail Demand—Southern Region				
RR Vol. =	-0.136 RR Rate	+0.576 GRP	-0.521 TK Rate	R^2 = 0.92
Tons	(0.181)	(0.175)	(0.444)	F = 28.3
Rail Demand—Western District				
RR Vol. =	-0.684 AV Rate	+0.213 GRP	+0.074 Rt. Ratio	R^2 = 0.58
Tons	(0.478)	(0.221)	(0.352)	F = 2.7
Rail Demand—Agriculture				
RR Vol. =	-0.837 RR Rate	+0.370 Crop Index	+0.661 TK Rate	R^2 = 0.94
Tons	(0.118)	(0.203)	(0.208)	F = 42.1
Rail Demand—Animals				
RR Vol. =	-0.207 RR Rate	-0.997 Livestk. Index	-1.115 TK Rate	R^2 = 0.95
Tons	(0.221)	(0.556)	(0.589)	F = 50.9
Rail Demand—Mines				
RR Vol. =	-0.819 RR Rate	+0.012 Mineral Prod.		R^2 = 0.67
Tons	(0.262)	(0.181)		F = 6.9
Rail Demand—Coal				
RR Vol. =	-0.128 RR Rate	+0.953 Coal Prod.		R^2 = 0.93
Tons	(0.268)	(0.167)		F = 53.6
Rail Demand—Forests				
RR Vol. =	-0.366 RR Rate	+0.762 Lumber Prod.	+0.410 TK Rate	R^2 = 0.82
Tons	(0.143)	(0.165)	(0.161)	
Rail Demand—Manufactures				
RR Vol. =	-0.391 RR Rate	+0.682 Manuf.	-1.105 TK Rate	R^2 = 0.82
Tons	(0.208)	(0.205)	(0.552)	F = 11.2
RR Vol. =	-0.670 RR Rate	+0.289 Manuf.		R^2 = 0.77
Tons	(0.167)	(0.066)		F = 12.6
Truck Demand—Aggregate				
TK Vol. =	-1.841 TK Rate	+2.323 GNP	+0.932 RR Rate	R^2 = 0.996
Ton-miles	(0.343)	(0.151)	(0.126)	F = 678.1

Note: All variables are in logarithmic form; coefficients are elasticities.

Let us see what composite picture of the demand for intercity freight transport we can construct from our estimates of the demand parameters. We will sketch rail demand first, then conclude with truck demand.

RAIL DEMAND

The first parameters to consider in measuring the strength of demand for the services of railroads are the income elasticities or, more precisely, the elasticities of rail volume with respect to the indexes of production. Interesting results emerge. The partial regression coefficient in the first equation in Table 3 shows that the elasticity of total rail ton-miles with respect to GNP in constant dollars is a meager +0.322. This is taken from the second equation shown for aggregate rail demand. (It is believed that this is a more accurate estimate of income elasticity in that the 0.63 estimate from the first equation is offset by a trend variable for which the cross-elasticity term is acting as proxy.) Growth in the economy is generating new traffic for the railroads (abstracting from changes in the rate level) at only one-third the rate at which the economy is expanding. This is presumed to result from the fact that the economy is growing primarily in service fields (including government services), which have negligible freight requirements, and in areas of industry that produce highly fabricated outputs for which the truck is better suited to transport.

Our equations show that growth in coal output and agricultural and forest products generates new railroad traffic the most consistently of all the other commodity groups. Coal has the highest elasticity of traffic with respect to production, +0.95, showing that coal traffic parallels coal production almost exactly, as we would expect. But none of our commodity groups has an elasticity exceeding unity, implying that there is no major sector of the economy that generates rail traffic even as fast as it itself grows. Manufacturing, an important source of high-rated traffic for the railroads, yields a low 2.9 percent increase in rail volume for each 10 percent increase in manufacturing output, reflecting the fact that growth in Manufactures is chiefly in products of high unit value that favor truck transport. (Again we are temporarily using the estimate from the equation that does not include the truck rate, which appears to be acting partially as proxy for a trend term.)

All of this suggests that the development of the economy itself is a major cause of the stagnant level of rail traffic. These parameters forebode trouble for the railroads in sustaining even a minimal growth rate, if the past 20 years are any clue to the future. If the railroads are to obtain any significant traffic growth, it will not be generated autonomously by the economy, but will have to come as the result of new pricing or market strategies by the railroads. We may be able to draw some conclusions about the efficacy of pricing strategies from the other demand parameters we have estimated, the price and cross-price elasticities.

The equations show that the price elasticities of railroad volumes are negative, as expected, for each of the commodity groups and regions shown. The first equation in Table 3 shows that the price elasticity of all rail traffic is -0.54, implying that a 10 percent increase in rail rates has had the effect of reducing volumes by only 5.4 percent less than proportionately. (It should be noted with some force that our equations consistently yield estimates of rail price elasticities between -1.0 and 0, not in one or two instances alone.) This estimated inelasticity of aggregate rail demand during the postwar years is a vindication of the efforts of railroad management to effect general rate increases faster than the ICC has generally been willing to allow.

If this result could be counted on to hold for the present, it would appear to recommend a policy of raising rail rates inasmuch as the railroads are on the inelastic portion of their aggregate demand curve. Further, insofar as diminished traffic will reduce total costs as well as expanding revenues, such a policy would augment profits even more. In theory, if marginal costs are positive, profit maximization calls for pricing to achieve a point on the demand curve where price elasticity is greater (more negative) than -1.0. If raising the general rate level is felt to be drawing too strong a policy conclusion from the estimates, at a minimum the consistently inelastic estimates caution very strongly against urging a policy of general rate reductions on the railroads.

Across-the-board reductions would substantially reduce total revenues and, at the same time, add new traffic and hence new costs.

This result of inelastic demand is repeated again and again among the commodity groups, suggesting that even across-the-board increases may not be inappropriate. Manufacturing shows an elasticity of only -0.39. Only Agriculture, with an elasticity of -0.84, is close to the revenue-maximizing unitary elasticity.

Caution must be exercised before turning these findings into actual recommendations for higher rail rates. These estimates are derived from time series so that there is no assurance that a broad interval of experience along the demand curve has been encompassed. In fact, all of our historical observations may have been drawn from a very short length of our hypothetical demand curve. We have predicated constant elasticity over this range, but there is no justification to assume—indeed, there is no reason to expect—that there is constant elasticity over a longer length of the demand curve. Conventionally, the higher rates are raised, the more elastic demand becomes; there is no way to determine from our estimates how far rates could be increased before the profit-maximizing elasticity is obtained. All that we may infer from these elasticities is that quite possibly rates should be adjusted initially or marginally upward.

The danger of upward adjustments of rail rates lies in the ever-present threat of traffic diversion to other modes. We may gain some insight into how great this danger is from examination of the cross-elasticities we have estimated. We are less successful in obtaining satisfactory estimates of the cross-elasticities, for in many cases these elasticities are negative when theory predicts positive elasticities. The cross-elasticity for all rail traffic from the first equation is -0.88, implying that rail volumes fall by 9 percent as truckers raise their rates 10 percent. Although these negative elasticities have little use as a direct policy guide, suggesting nonsensically that the motor carriers could destroy the railroads by raising their own rates sufficiently, they do have a valid and very interesting historical interpretation. The trend of truck rates during the postwar period has been consistently upward as the data in the Appendix show. The negative cross-elasticity should be interpreted not as a cross-elasticity as such, but as the coefficient of a trend variable representing the steady diversion of traffic from rail to truck (a surmise that deserves explicit testing by the inclusion of a trend in the equations): What the high negative cross-elasticity signals is a persistent ability of the trucks to capture increasing quantities of traffic despite their steady rate increases.

We find this high diversion trend in the demand equation not only for the aggregate of all rail traffic but, even to a greater degree, for Manufactures for which the elasticity is -1.11. Only for two commodity groups, Agriculture and Forests, has the "diversion-trend effect" been offset by the cross-elasticity effect, yielding a properly positive cross-elasticity. As truck rates have increased by 10 percent the quantity of agricultural goods hauled by rail has risen by 6.6 percent, and the quantity of forest products going by rail has risen 4.1 percent. The implication is that the rails have done best at retrieving agricultural and forest traffic after trucks have raised their rates.

Let us proceed further with our efforts to get at the cross-elasticity between rail volumes and truck rates. We expressed fear in an earlier discussion that truck rates might prove collinear with rail rates and, therefore, create two orthogonal series from the two rate series by taking the average rate and truck-rail rate ratio. The collinearity we feared did not materialize; instead, however, the truck rate index appears to be acting as a proxy for a rail-to-rate diversion trend. To escape this new problem let us revert to our orthogonalized variables. If the coefficient of the truck-rail rate ratio is (a) positive and (b) significantly different from zero, this would be evidence that the division of traffic is sensitive to the rate relationship. We record below the approximate t-ratio for each market for which the rate-ratio coefficient is of the proper algebraic sign.

All Rail Freight	3 ?	Pocahontas Region	3 ?	Agriculture	7	Coal	-
		Southern Region	2 ?	Animals	-	Forests	2.5
Eastern District	-	Western District	2 ?	Mines	-	Manufacturing	3 ?

The estimates are not as stable as we would like; the question marks indicate widely varying coefficients, some of which are significant at the t-ratio shown. For the aggregate rail demand equation we get an uncertain t-ratio of about 3, possible confirmation of the fact that rail volumes are sensitive to the relationship of rail rates to truck rates. We get similar confirmation in the transport market for Manufactures. The two markets in which we have the most certain evidence of a significant cross-elasticity are those for agricultural and forest products. These are the same two markets for which we got positive direct estimates of cross-elasticity earlier.

We conclude that railroads may be well advised to adjust their rates marginally upward, but this is an adjustment that cannot be made indiscriminately. The advancement of rates should be a cautious one, for we do not know how far our demand curve can be extrapolated; and the division of traffic between rail and other modes is more sensitive to relative rates in some sectors than in others.

TRUCK DEMAND

Our analysis of the demand for truck transport is considerably briefer because of our inability to disaggregate by regions or commodity groups. The basic demand equation, all in logs, is reproduced below.

$$\begin{array}{llllll} \text{TK Vol.} = & -1.841\ \text{TK Rate} & +2.323\ \text{GNP} & +0.932\ \text{RR Rate} & R^2 = 0.996 \\ \text{Ton-miles} & \quad(0.343) & \quad(0.151) & \quad(0.126) & F\ = 678.1 \end{array}$$

The t-ratios and F-ratio are all highly significant; virtually all variance has been accounted for.

Our expectation that growth in the economy has contributed more liberally to growth in truck traffic than to that in rail traffic is confirmed; truck volumes have expanded about two and a third times as fast as the GNP (in constant dollars). The growth prospects of the trucking industry appear excellent.

The equation shows a surprisingly large own-price elasticity, indicating that truck volumes fall 18 percent if truck rates are raised 10 percent or, conversely, that truck volumes will increase 18 percent if rates are cut by only 10 percent. Without knowing marginal costs and revenues exactly, it is only possible to say that the profit-maximizing elasticity would be somewhat greater (more negative) than -1.0. Given the extent of competition in the trucking industry, it seems likely that the estimated -1.8 elasticity is close to that profit-maximizing amount. Thus, we have little reason to expect major movements in truck rates in either direction, and railroads are unlikely to obtain that freedom to raise their rates with impunity that would be granted by substantially higher truck rates.

It is curious that our equation finds a strong negative own-price elasticity of truck traffic despite the fact that, in the analysis of rail demand, the estimates of cross-price elasticity show that rail traffic declines even as the trucks are raising their rates. Wha has apparently happened in the truck analysis is that our rail-to-truck diversion trend appears as a large income elasticity, leaving the rate variables to pick out "true" price elasticities.

The final parameter of our truck demand equation, the cross-elasticity with respect to rail rates, is properly positive, +0.93. This finding is well confirmed by the equation using the orthogonalized B-set of variables; the coefficient on the truck-rail rate ratio is six and a half times the standard error. Truck traffic, therefore, is certainly sensitive to the level of rail rates, and the motor carrier industry is well advised to keep the rate relationship in mind when setting rates, as they most certainly do.

In general, we find that the trucking industry is on an expansionary growth path. The maintenance of a proper truck rate level, especially with respect to the rail rate, must be a major consideration of the trucking industry in sustaining this exuberant growth.

SUMMARY AND IMPLICATIONS FOR PUBLIC POLICY

We summarize our results by considering the aggregate demand equation for rail traffic as a unit, then for truck traffic. The rail equation, all in logs is

$$\begin{array}{lllll} \text{RR Vol.} = & -0.537\ \text{Rate} & +0.628\ \text{GNP} & -0.730\ \text{TK Rate} & R^2 = 0.79 \\ \text{Ton-miles} & (0.202) & (0.241) & (0.549) & F = 8.9 \end{array}$$

This equation shows that growth in the GNP is generating new rail traffic at only three-fifths the rate the economy is expanding. (We have explained elsewhere that a better estimate might be only one-third.) What rate strategy can the railroads adopt to ameliorate this situation? The outlook is dim; the railroads can probably gain, on balance, by raising their rates at least marginally, because their own-price elasticity of demand appears to be only slightly different from -0.5, indicating an inelastic market. However, we have evidence that the division of aggregate traffic is sensitive to the relationship between truck and rail rates; thus, the rails cannot push the strategy of raising rates too far, and the recommended policy for rail profit-maximization appears to be a selective readjustment of rates tending upward on balance.

The structure of demand is repeated basically unchanged in the regional markets and in the commodity-group markets we have surveyed. Manufactures are an important source of high-rated traffic for the railroads. Yet this traffic is expanding far slower than the manufacturing industry. Marginal rate increases are called for by price inelasticity; yet this traffic is certainly sensitive eventually to the relationship of rail-to-truck rates. The markets for transport of agricultural and forest products are also shown sensitive to relative rates. Only the markets for transport of animal products and minerals, including coal, do not show this same sensitivity.

This picture of demand, drawn from the past, offers little encouragement for the future. Restricted to pricing strategies, the very best that could happen to railroads would be for truckers to increase their rates substantially, after which the rails could increase their rates, and profits, with impunity. But we have seen that there is no reason to anticipate the cooperation of truckers in this strategy, so that the railroads appear boxed in with their present diminished share of the market and negligible growth rate. Significant growth in rail traffic will not be achieved by movements along the present demand curve, but only by shifts of the entire demand schedule. This will only be accomplished by bold changes in rail marketing strategy.

The trucks have no similar worries about sustaining the growth of their industry, judging only from the past; the economy is generating new truck traffic at more than twice its own rate of growth. But truck traffic in total appears to be sensitive to prices. The motor carriers may raise their prices over time to adjust for inflation and technological improvements and still maintain this growth rate; yet the path those prices follow upward appears to be a narrow one. The diversion of traffic to other modes will swiftly follow any deviation from that path, as witnessed by the high price elasticity and cross price elasticity of demand for truck transport.

We end with a few words about the implications of our findings for public policy. In one estimate after another we have found evidence that the division of traffic between rail and truck is sensitive to the relative rate level, though more so for some sectors of the economy than for others. We may offer this in evidence against the ICC's apparent belief that the market is incapable of policing freight rates and urge the ICC to move toward greater reliance on market forces as it evolves its rate policies. The demand equation we have estimated for the trucking market offers no evidence for belief in the absence of competitively determined rates from that market. Private and contract trucking almost surely provides this competition.

The equations for the rail market consistently indicate inelastic demand. If the ICC desires to permit the railroads to improve short-run profits, marginal rate increases will probably be effective. We may state the converse more firmly: There is no reason to believe that across-the-board rate reductions will improve rail profits.

Growth in the economy is generating very little new railroad traffic; price-inelastic demand implies that greater price competition will not succeed in drawing substantial volumes of new traffic to the rails. Rate juggling is a game with a small pot, even if the railroads succeed in winning it. The efforts of management are better applied elsewhere. New marketing strategies to shift the demand curve are called for if the railroads are to achieve a greater rate of growth. It is believed that present ICC policies help to divert the efforts of railroad management toward rate matters and away from providing a broader range of services in transport markets. The Commission must encourage a redirection of efforts, principally by working toward an early resolution of the rate conundrum.

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Appendix C

Regression Equations

ALL CLASSES - ENTIRE U. S.
Tons of RR Freight
1947 - 1966

	RR RATE	GNP/ $1958	TRUCK RATE	R^2	F-RATIO
1.	-.510 (.158)			.604	10.4
2.		-.075 (.087)		.200	0.8
3.			-.265 (.168)	.348	2.5
4.	-.594 (9.7)	+.069 (.085)		.624	5.4
5.	-.562 (.217)		+.072 (.196)	.608	5.0
6.		+.647 (.263)	-1.529 (.534)	.593	4.6
7.	-.403 (.231)	+.437 (.276)	-.878 (.628)	.675	4.5

ALL FREIGHT - ENTIRE U. S.
Tons of RR Freight
1947 - 1966

	AV. RATE	RATE RATIO	GNP/ $1958	R^2	F-RATIO
1.	-.439 (.178)			.502	6.1
2.		+.244 (.221)		.252	1.2
3.			-.075 (.087)	.200	0.8
4.	-.488 (.171)	+.333 (.189)		.606	4.9
5.	-1.060 (.303)		+.313 (.130)	.665	6.7
6.		+.555 (.252)	-.203 (.098)	.503	2.9
7.	-1.282 (.532)	-.197 (.384)	+.439 (.280)	.672	4.4

ALL FREIGHT - ENTIRE U. S.
Ton-Miles of RR Freight
1947-1966

	RR RATE	GNP/ $1958	TRUCK RATES	R^2	F-RATIO
1.	-.301 (.197)			.340	2.3
2.		+.153 (.086)		.388	3.2
3.			+.175 (.185)	.218	0.9
4.	-.696 (.166)	+.322 (.074)		.763	11.9
5.	-.766 (.210)		+.634 (.190)	.682	7.4
6.		+.908 (.253)	-1.598 (.514)	.677	7.2
7.	-.537 (.202)	+.628 (.241)	-.730 (.549)	.790	8.9

ALL FREIGHT - ENTIRE U. S.
Ton-Miles of RR Freight
1947-1966

	AV. RATE	RATE RATIO	GNP/ $1958	R^2	F-RATIO
1.	-.025 (.216)			.027	0.0
2.		+.680 (.179)		.667	14.4
3.			+.153 (.086)	.388	3.2
4.	-.129 (166)	+.704 (.184)		.681	14.7
5.	-1.204 (.263)		+.593 (.113)	.787	13.8
6.		+.688 (.229)	-.005 (.089)	.667	6.8
7.	-1.266 (.467)	-.054 (.336)	+.628 (.246)	.787	8.7

ALL FREIGHT - ENTIRE U. S.
Tons of Truck Freight
1947 - 1966

	RR RATE	GNP/ $1958	TRUCK RATE	R^2	F-RATIO
1.	+1.651 (.623)			.530	7.0
2.		+1.359 (.062)		.982	486.3
3.			+2.569 (.271)	.913	89.9
4.	-.247 (.170)	+1.365 (.076)		.982	230.0
5.	-.415 (.400)		+2.818 (.361)	.918	45.7
6.		+1.880 (.186)	-1.102 (.378)	.988	348.6
7.	+.334 (.157)	+2.054 (.188)	-1.643 (.428)	.991	281.9

ALL FREIGHT - ENTIRE U. S.
Tons of Truck Freight
1947 - 1966

	AV. RATE	RATE RATIO	GNP/ $1958	R^2	F-RATIO
1.	+2.634 (.439)			.816	35.9
2.		+1.972 (.704)		.551	7.9
3.			+1.359 (.062)	.982	486.3
4.	+2.407 (.312)	+1.534 (.346)		.919	46.4
5.	-.245 (.276)		+1.449 (.119)	.983	240.7
6.		-.178 (.199)	+1.400 (.077)	.983	240.9
7.	-1.322 (.362)	-.954 (.261)	+2.062 (.191)	.991	281.5

ALL FREIGHT - ENTIRE U. S.
Ton-Miles of Truck Freight
1947 - 1966

	RR RATE	GNP/ $1958	TRUCK RATES	R^2	F-RATIO
1.	+2.433 (.703)			.632	12.0
2.		+1.680 (.076)		.982	494.0
3.			+3.254 (.289)	.936	127.2
4.	+.529 (.165)	+1.551 (.073)		.989	380.4
5.	+.084 (.438)		+3.204 (.396)	.936	60.2
6.		+1.838 (.276)	-.335 (.562)	.983	238.3
7.	+.932 (.126)	+2.323 (.151)	-1.841 (.343)	.996	678.1

ALL FREIGHT - ENTIRE U.S.
Ton-Miles of Truck Freight
1947 - 1966

	AV. RATE	RATE RATIO	GNP/ $1958	R^2	F-RATIO
1.	+3.507 (.447)			.880	61.6
2.		+2.047 (.923)		.463	4.9
3.			+1.680 (.076)	.982	494.0
4.	+3.293 (.342)	+1.448 (.379)		.937	61.3
5.	+.619 (.313)		+1.453 (.134)	.986	289.0
6.		-.823 (.150)	+1.869 (.058)	.994	660.1
7.	-.921 (.289	-1.363 (.209)	-2.330 (.152)	.996	679.6

EASTERN REGION
1947 - 1966

	RR RATE	GNP/ EASTERN	TRUCK RATE	R^2	F-RATIO
1.	-1.094 (.[illegible])			.741	21.9
2.		-.641 (.128)		.763	25.1
3.			-1.280 (.190)	.846	45.4
4.	-.642 (.251)	-.414 (.143)		.835	19.6
5.	-.414 (.253)		-.978 (.259)	.869	26.2
6.		+.581 (.373)	-2.286 (.671)	.867	25.7
7.	-.317 (.267)	+.425 (.391)	-1.786 (.786)	.878	18.0

EASTERN DISTRICT
1947 - 1966

	AV. RATE	RATE RATIO	GNP/ EASTERN	R^2	F-RATIO
1.	-1.391 (.195)			.860	51.0
2.		-.224 (.461)		.114	0.2
3.			-.641 (.128)	.763	25.1
4.	-1.393 (.195)	-.240 (.237)		.868	26.1
5.	-1.286 (.399)		-.063 (.207)	.861	24.3
6.		+.503 (.319)	-.732 (.136)	.797	14.8
7.	-2.132 (.689)	-.687 (.464)	+.441 (.395)	.879	18.0

POCAHONTAS REGION

1947 - 1966

	RR RATE	GNP/ POCAHONTAS	TRUCK RATE	R^2	F-RATIO
1.	-.430 (.337)			.289	1.6
2.		+.290 (.153)		.408	3.6
3.			+.295 (.313)	.217	0.9
4.	-1.168 (.288)	+.611 (.138)		.759	11.5
5.	-1.331 (.384)		+1.157 (.350)	.665	6.7
6.		+1.320 (.396)	-2.086 (.757)	.651	6.2
7.	-.964 (.368)	+.925 (.374)	-.749 (.829)	.772	7.9

POCAHONTAS REGION

1947 - 1966

	AV. RATE	RATE RATIO	GNP/ POCAHONTAS	R^2	F-RATIO
1.	-.007 (.361)			.005	0.0
2.		+1.217 (.331)		.655	13.5
3.			+.290 (.153)	.408	3.6
4.	-.170 (.281)	+1.249 (.341)		.664	6.7
5.	-1.870 (.444)	+1.024 (.206)	+1.024 (.206)	.770	12.4
6.		+1.164 (.414)	+.035 (.159)	.657	6.4
7.	-1.725 (.679)	+.155 (.536)	+.933 (.379)	.771	7.8

SOUTHERN REGION

1947 - 1966

	RR RATE	GNP/ SOUTH	TRUCK RATE	R^2	F-RATIO
1.	-.217 (.343)			.148	0.4
2.		+.374 (.044)		.893	70.5
3.			+.829 (.147)	.798	31.6
4.	-.260 (.148)	+.376 (.042)		.910	40.9
5.	-.469 (.188)		+.894 (.132)	.857	23.5
6.		+.650 (.143)	-.716 (.355)	.914	43.3
7.	-.136 (.181)	+.576 (.175)	-.521 (.444)	.917	28.3

SOUTHERN REGION

1947 - 1966

	AV. RATE	RATE RATIO	GNP/ SOUTH	R^2	F-RATIO
1.	+.866 (.294)			.571	8.7
2.		+.769 (.128)		.818	36.3
3.			+.374 (.044)	.893	70.5
4.	+.434 (.207)	+.660 (.128)		.859	23.8
5.	-.489 (.237)		+.479 (.065)	.915	43.7
6.		+.205 (.187)	+.296 (.083)	.900	36.2
7.	-.670 (.379)	-.172 (.277)	+.582 (.180)	.917	28.2

WESTERN DISTRICT

1947 - 1966

	AV. RATE	RATE RATIO	GNP/ WEST	R^2	F-RATIO
1.	-.194 (.147)			.298	1.8
2.		+.322 (.174)		.399	3.4
3.			-.005 (.059)	.019	0.0
4.	-.244 (.134)	+.372 (.167)		.543	3.6
5.	-.767 (.264)		+.253 (.102)	.576	4.2
6.		+.489 (.206)	-.091 (.064)	.498	2.8
7.	-.684 (.478)	+.074) (.352)	+.213 (.221)	.578	2.7

AGRICULTURE

1947 - 1966

	RAIL RATE	CROP PROD.	TRUCK RATE	R^2	F-RATIO
1.	-.224 (.233)			.221	0.927
2.		+.740 (.168)		.721	19.5
3.			+.504 (.166)	.582	9.24
4.	-.595 (.115)	+.973 (.117)		.902	37.0
5.	-.926 (.114)		+.985 (.097)	.930	54.5
6.		+.994 (.370)	-.241 (.312)	.732	9.82
7.	-.837 (.118)	+.370 (.203)	+.661 (.208)	.942	42.1

AGRICULTURE

1947 - 1966

	AV. RATE	RATE RATIO	CROP PROD.	R^2	F-RATIO
1.	+.277 (.234)			.268	1.4
2.		+.967 (.091)		.929	112.5
			+.740 (.168)	.721	19.5
4.	+.059 (.095)	+.954 (.095)		.930	54.5
5.	-.645 (.211)		+1.222 (.210)	.831	18.9
6.		+.844 (.119)	+.180 (.117)	.938	61.7
7.	-.175 (.158)	+.756 (.143)	+.369 (.207)	.942	42.1

ANIMALS

1947 - 1966

	RR RATE	LIVESTOCK INDEX	TRUCK RATE	R^2	F-RATIO
1.	-1.256 (.443)			.556	8.0
2.		-2.146 (.200)		.930	115.4
3.			-2.177 (.186)	.940	136.4
4.	-.350 (.211)	-1.979 (.216)		.940	64.7
5.	-.140 (.221)		-2.099 (.226)	.941	66.1
6.		-.900 (.547)	-1.322 (.549)	.948	76.0
7.	-.207 (.211)	-.977 (.556)	-1.115 (.589)	.951	50.9

ANIMALS

1947 - 1966

	AVER. RATE	RATE RATIO	LIVESTOCK PROD.	R^2	F-RATIO
1.	-2.244 (.310)			.863	52.4
2.		-.920 (.522)		.384	3.1
3.			-2.146 (.200)	.930	115.4
4.	-2.235 (.214)	-.901 (.197)		.941	65.6
5.	-.796 (.355)		-1.568 (.315)	.947	73.1
6.		+.207 (.239)	-2.242 (.230)	.933	57.3
7.	-1.311 (.55)	-.403 (.333)	-1.005 (.558)	.951	50.6

MINES

1947 - 1966

	RR RATE	MINERAL PROD.	TRUCK RATE	R^2	F-RATIO
1.	-.809 (.212)			.668	14.5
2.		-.300 (.184)		.359	2.7
3.			-.698 (.176)	.683	15.7
4.	-.819 (.262)	+.012 (.181)		.668	6.9
5.	-.421 (.322)		-.423 (.272)	.718	9.0
6.		+1.018 (.214)	-1.806 (.262)	.878	28.6
7.	+.104 (.259)	+1.065 (.250)	-1.926 (.401)	.879	18.2

MINES

1947 - 1966

	AV. RATE	RATE RATIO	MINERAL PROD.	R^2	F-RATIO
1.	-.839 (.192)			.717	19.1
2.		-.299 (.371)		.187	0.6
3.			-.300 (.184)	.359	2.7
4.	-.844 (.206)	+.025 (.282)		.717	9.0
5.	-1.363 (.282)		+.473 (.202)	.796	14.7
6.		+0.150 (.485)	-.352 (.253)	.365	1.3
7.	-1.833 (.271)	-.967 (.303)	+1.076 (.250)	.881	18.4

COAL

1947 - 1966

	RR RATE	COAL PROD.	TRUCK RATE	R^2	F-RATIO
1.	-1.363 (.262)			.775	27.1
2.		+1.017 (.096)		.928	111.8
3.			-.955 (.229)	.701	17.4
4.	-.128 (.268)	+.953 (.167)		.929	53.6
5.	-.974 (.299)		-.500 (.232)	.829	18.6
6.		+.842 (.064)	-.470 (.079)	.977	179.7
7.	+.337 (.155)	+.983 (.087)	-.546 (.080)	.982	147.6

COAL

1947 - 1966

	AV. RATE	RATE RATIO	COAL PROD.	R^2	F-RATIO
1.	-1.370 (.234)			.810	34.4
2.		-.205 (.391)		.123	0.3
3.			+1.017 (.096)	.928	111.8
4.	-1.473 (.245)	+.297 (.242)		.827	18.4
5.	-.586 (.146)		+.765 (.095)	.964	110.7
6.		-.536 (.082)	+1.087 (.054)	.980	205.3
7.	-.214 (.139)	-.431 (.104)	+.981 (.086)	.983	148.9

FORESTS

1947 - 1966

	RR RATE	LUMBER PROD.	TRUCK RATE	R^2	F-RATIO
1.	-.168 (.127)			[illegible]	1.8
2.		+.819 (.181)		.730	20.5
3.			-.124 (.151)	.019	0.0
4.	-.068 (.953)	+.785 (.190)		.739	10.2
5.	-.493 (.209)		+.449 (.238)	.497	2.8
6.		+.843 (.187)	+.0748 (.106)	.739	10.2
7.	-.366 (.143)	+.762 (.165)	+.410 (.161)	.823	11.2

FORESTS

1947 - 1966

	RR RATE	MINERAL PROD.	TRUCK RATE	R^2	F-RATIO
1.	-.106 (.147)			.169	0.5
2.		+.486 (.202)		.493	5.8
3.			+.819 (.181)	.730	20.5
4.	-.430 (.136)	+.472 (.212)		.497	2.8
5.	-.001 (.107)		+.819 (.191)	.730	9.7
6.		+.375 (.139)	+.747 (.158)	.820	17.5
7.	+.044 (.094)	+.387 (.145)	+.763 (.165)	.823	11.2

MANUFACTURING

1947 - 1966

	RR RATE	INDEX OF MANUF.	TRUCK RATE	R^2	F-RATIO
1.	-.377 (.217)			.379	3.0
2.		+.183 (.082)		.465	5.0
3.			+.222 (.216)	.236	1.1
4.	-.670 (.167)	+.289 (.066)		.772	12.6
5.	-.772 (.219)		+.644 (.207)	.675	7.1
6.		+.895 (.184)	-1.801 (.439)	.779	13.1
7.	-.391 (.208)	+.682 (.205)	-1.105 (.552)	.823	11.2

MANUFACTURING

1947 - 1966

	AV. RATE	RATE RATIO	INDEX OF MANUF.	R^2	F-RATIO
1.	-.047 (.255)			.043	0.0
2.		+.700 (.186)		.664	14.2
3.			+.183 (.082)	.465	5.0
4.	-.124 (.196)	+.712 (.190)		.674	7.1
5.	-1.167 (.250)		+.516 (.091)	.810	16.2
6.		+.651 (.246)	+.029 (.092)	.667	6.8
7.	-1.490 (.448)	-.302 (.347)	+.680 (.209)	.820	10.9

The Structure of Congestion Costs and Optimum Pricing in Inland Waterway Transportation

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•THIS PAPER describes the nature of a computer simulation model that analyzes the congestion costs of and the benefits accruing from improvements to an inland (shallow water) transportation system such as that found on the major navigable rivers of the United States. Some specific application of the model will be illustrated. The reasons for constructing the model were (a) that congestion, which frequently occurs on the major rivers of the United States, not only increases the physical capacity of the waterways beyond their current status but also has become extremely expensive; (b) that analysis of the impact of structural improvements on congestion costs is quite difficult in a complex system; and (c) that efficient use of the waterways in the face of congestion requires the pricing of the services of the waterway in such a way that the prices charged reflect congestion costs.

The model is a computer simulation model capable of representing the flows of commercial barge tows over a waterway system consisting of (a) channel segments of assignable lengths, widths, depths, and currents, (b) ports with specified types of delays, (c) locks of specific characteristics, which may include different numbers of chambers and any distributions of locking time components, and (d) restricted stretches, if applicable, such as those in which speeds must be restricted or in which passing may be prohibited. The traffic itself consists of any specified mix of characteristics of modern tows that arrive at the ends of the system at specified average rates per day but whose actual arrival times are randomly distributed. The components of locking times are also randomly generated.

Various statistics compiled on the operations of the system include the number of tows and barges processed at each lock, average queue lengths at each lock, total delay times in queues, total gross tonnage, total delay costs, and total system operating costs. Optional outputs permit tracing of individual tow movements, costs, and delay times. [For a more complete description of the model, see Howe (1).]

The costs incurred on the waterway system consist of the public costs of constructing and operating the waterway and the private costs of operating tows on it. The variable public costs are extremely low in almost all areas. The variable private costs can be divided into those that are incurred by operating on the system when no congestion is present and those that are incurred because of congestion. The first category of private operating costs are, by definition, not variable with the volume of traffic and are reflected in the height of the demand curve for the service of the waterway (Fig. 1). The congestion costs will be zero up to some traffic level and then begin to increase as queues grow at locks, ports, and other restricted points of the system. This growth of delay costs may be represented by the average delay cost (ADC) and marginal delay cost (MDC) functions of Figure 1.

The economically efficient volume of traffic on the waterway, Q^*, is the volume at which marginal delay cost just equals the willingness of the marginal waterway user to pay (demand value). For reasons that have been amply explained elsewhere (2), the likely equilibrium level of traffic will be at Q^e in the absence of appropriate tolls. At

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TABLE 1

INPUTS, OUTPUTS, AND DELAY COSTS OF A THREE-DAM RIVER SYSTEM

Expected Arrival Rates per Day		Total Tows Into System in 30.6 Days (actual)	Total System Delay Cost Over 30.6 Days ($)	Average Delay Cost per Tow Into System ($)	Marginal Delay Cost per Tow ($)
Up	Down				
10	10	598	22, 900	38	–
12	12	736	36, 800	50	101
14	14	854	68, 000	80	265
16	16	987	118, 900	120	382
18	18	1, 092	217, 400	199	938
20	20	1, 214	587, 600	484	3, 035

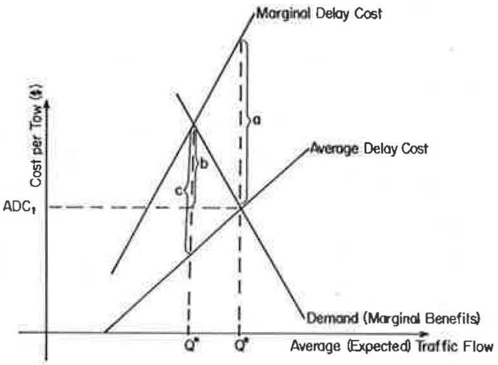

Figure 1. Growth of delay costs represented by functions of average delay and marginal delay costs.

TABLE 2

LOCAL AND SYSTEM SAVINGS IN DELAY TIME OVER 30.6 DAYS AFTER IMPROVEMENTS TO LOCK 2

Arrival Rates	Apparent Savings at Lock 2 (min)	Actual System Savings (min)
Up = 16 Down = 16	48, 767	52, 347
Up = 22	1, 515, 775	989, 972

TABLE 3

AVERAGE QUEUE LENGTHS AFTER IMPROVEMENTS TO LOCK 2

(Arrival Rates = 22 per Day)

Lock		Average Queue Length Before Change	Average Queue Length After Change
1:	Up	5.37	10.13
	Down	5.75	11.34
2:	Up	16.30	0.12
	Down	18.43	0.16
3:	Up	0.88	1.62
	Down	1.20	2.07

this level, marginal delay costs are far in excess of the marginal value of traffic on the river by the amount a. A toll in the amount of c dollars per tow passage would efficiently bring about the optimum level of traffic.

How can these schedules of congestion costs be derived? It is almost impossible to derive them from historical statistics because the cost figures have never been kept, and the historical range of values does not cover what is generally needed—forecasts of future conditions. The simulation model makes it possible to generate the needed congestion cost data.

Table 1 gives partial program output when the model was run for a small system that has three dams located approximately 100 miles apart. (This model closely resembles the reaches of the Ohio River, starting with Meldahl Lock and Dam and extending downstream just past McAlpine Lock and Dam.) The average (expected) arrival rates of traffic were simultaneously augmented in both directions. The points to note are the rapid increase in total, average, and marginal delay costs.

A second point investigated by the model was the extent of divergence between locally observable benefits stemming from a system improvement (such as increasing the capacity of a lock) and the benefits accruing to the entire system. The motive for investigating this was an often-voiced suspicion that local and system benefits may diverge widely. Running the model to a month's activity at two different traffic-arrival rates before and after improvements at Lock 2 measured the benefits in terms of minutes of delay time saved both at Lock 2 and for the entire system. (The actual operating costs of the tows used in this run of the model averaged very close to $1 per min.)

TABLE 4

CHARACTERISTICS OF SYSTEM PERFORMANCE FOR INCREMENTS OF UPBOUND SMALL TOWS[a]

(8 Barges, 2,000 Horsepower)

Upbound Arrival Rate, Small Tows	Total System Cost ($000)	Total Delay Cost ($)	Total Ton-Miles Produced (millions)	Total No. Tows Into System	Average Total Cost per Million Ton-Miles ($)	Average Delay Cost per Million Ton-Miles ($)	Average Delay Cost per Tow Into System ($)	Marginal Delay Cost per Tow Into System ($)	Average Delay Cost per Tow Locked ($)		
									Lock 1	Lock 2	Lock 3
5	2, 110	52, 980	3, 055	870	690	17	61	–	24	21	11
7	2, 311	62, 618	3, 207	950	720	20	66	120	27	20	16
9	2, 564	90, 432	3, 457	1, 048	740	26	86	284	33	32	19
11	2, 741	119, 920	3, 641	1, 123	750	33	107	393	40	44	24
13	2, 981	144, 027	3, 848	1, 215	770	37	119	262	44	49	29
15	3, 416	191, 095	3, 820	1, 254	890	50	152	1, 207	38	80	38

[a] Downbound arrival rate = 16 per day and upbound arrival rate = 5 per day, over a period of 34.7 days.

TABLE 5

CHARACTERISTICS OF SYSTEM PERFORMANCE FOR INCREMENTS OF UPBOUND LARGE TOWS[a]

(17 Barges, 3,200 Horsepower)

Upbound Arrival Rate, Large Tows	Total System Cost ($000)	Total Delay Cost ($)	Total Ton-Miles Produced (millions)	Total No. Tows Into System	Average Total Cost per Million Ton-Miles ($)	Average Delay Cost per Million Ton-Miles ($)	Average Delay Cost per Tow Into System ($)	Marginal Delay Cost per Tow Into System ($)	Average Delay Cost per Tow Locked ($)		
									Lock 1	Lock 2	Lock 3
5	2, 119	52, 980	3, 055	870	690	17	61	–	24	21	11
7	2, 439	82, 458	3, 377	972	720	24	85	289	34	30	15
9	2, 650	102, 326	3, 720	1, 044	710	28	98	276	35	35	25
11	2, 908	151, 342	3, 916	1, 119	740	39	135	654	34	55	45
13	3, 223	201, 568	4, 314	1, 191	750	47	169	698	46	64	53
15	3, 531	365, 012	4, 520	1, 262	780	81	289	2, 302	46	126	109

[a] Downbound arrival rate = 16 per day and upbound arrival rate = 5 per day, over a period of 34.7 days.

It appears that at the lower traffic rate, system-wide benefits somewhat exceed those measured only at Lock 2; but at the higher traffic rate, local benefits clearly overstate system benefits (Table 2). The importance of this observation to system planning and benefit-cost analysis is obvious. The actual transfers of delay time from one lock in the system to the others, which underlie the savings figures of Table 2, are given in Table 3. Again, at the higher traffic rate, the improvement of Lock 2 causes a significant part of the delay time to be shifted to Locks 1 and 3.

It would be expected that different types of traffic would impose different degrees of congestion cost on the system. The characteristics of the tows that might affect their contribution to system delay costs would include size (number of barges), draft, and direction of travel. Various runs of the model make it quite clear that these differential effects hold. Tables 4 and 5 give the results of the analysis of the differential impacts of large and small tows on system delay costs. The marginal delay cost per tow increases much more rapidly when the arrival rate of large tows is increased than when that of small tows is increased. The average total cost per million ton-miles (delay plus noncongested operating costs) increases less rapidly for the large tows, however, because the running economies of the large tows tend somewhat to offset their greater contribution to delay costs.

The usefulness of this model extends to the analysis of other problems, and it can be used for any waterway system. The program is currently being used by and is available from Professor Joseph L. Carroll, Transportation and Traffic Safety Center, Pennsylvania State University, University Park.

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